

History of Architecture and Ancient Building Materials in India



SATISH CHANDRA



ABOUT THE BOOK

'History of Architecture and Ancient Building Materials in India' consists of two parts. The first part deals with the architecture of India and the second part is about the ancient building materials. The aim of the book is not to go into detail about the architectural history of India but to give an impression and awareness about the architectural skills existed in the ancient period and how it differed during the different rulers who invaded India.

The second part deals with the building materials used in the ancient period, which is a unique contribution. It provides the information about the materials specifically the natural polymers, used in the ancient period, and the technique of their application. Most interesting part is the scientific explanations and the narrations about the mechanisms involved in the interactions of the ingredients used in the construction, which enhanced the durability properties of the structure. The materials ascribed are not only from India, some plasters and mortar compositions used in the other part of the world are also described. It is a very valuable and comprehensive piece of work and will be a guide book for the practicing engineers, restorers, conservators, archaeologists, historians and also for the people in general interested in the building materials.

The book carries Foreword by Ingval Maxwell, DA Dun, RIBA, FRIAS, AABC, FSA Scot, Director, Technical Conservation, Research and Education Division Historic Scotland, Edinburgh, Scotland and R.S. Bisht Director in the Archaeological Survey of the Government of India, at New Delhi.

The prime objective of this remarkable book is about the chemistry & analysis of the materials used in our ancient monuments, today standing as a symbol of our cultural heritage, after thousands of years. A need was felt to have an indepth study of chemistry of the ancient building materials used in the construction of these ancient monuments in their relation, as to the chemistry of cement and its binding properties and durability of structures.

**History of Architecture
and
Ancient Building Materials
in India Part I & II**
(in single volume)

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TECH BOOKS INTERNATIONAL
NEW DELHI 110 019, INDIA

*Dedicated
To My Respected Father*

PREFACE

The book consists of two parts. The first part deals with the architecture of India and the second part is about the ancient building materials. The aim of the book is not to go into detail about the architectural history of India but to give an impression and awareness about the architectural skills existed in the ancient period and how it differed during the different rulers who invaded India.

The second part deals with the building materials used in the ancient period, which is an unique contribution. It provides the information about the materials specifically the natural polymers, used in the ancient period, and the technique of their application. Most interesting part is the scientific explanations and the narration's about the mechanisms involved in the interactions of the ingredients used in the construction, which enhanced the durability properties of the structure. The materials ascribed are not only from India, some plasters and mortar compositions used in the other part of the world are also described. It is a very valuable and comprehensive piece of work and will be a guide book for the practicing engineers, restorers, conservator's, archaeologists, historians and also for the people in general interested in the building materials.

Man's basic needs after food and clothing has always been protection from the weather, from heat of the sun, from torrential rains and from cold. The very first time man realized the concept of building when assembled near the fire and have hidden themselves in between the stones, protecting from cold. This has awakened the idea of using stones as a protection from the rough weather. It was copper age and the steel was unknown so there were no chisel and hammer. Stones were used for making the tools. Thus stone caves were constructed as shelters. Later attempts were made to provide these shelters in a simple way: Screens and windbreaks of interwoven branches and walls of trues or slabs piled one upon the other. He slowly acquired, by practical experience, knowledge of the elementary principles of building: how best for example to stabilize the structure. The basic raw material was stones and clay. Clay structures produced erosion in heavy rain, and cracked in hot weather. These were stabilized by the addition of different organic and inorganic materials. Organic materials used were natural products mostly Agro-products, and the inorganic materials were lime and other pozzolanic materials such as surkhi, rakhi, etc. The durability was further improved by mixing aggregates like sand and stones. Through the ages man searched continuously for new and better material with which to build and decorate his structures, and these new material often demanded

new techniques of application. The ancient builders were very well versed with the knowledge and technique of construction. Some of the structures are still standing in acceptable shape today speaks about their durability. Some of the examples are the recent excavations done by the archaeological survey, Dholavira, Kalbangan built about 3000 B.C. Besides the well known twin cities of Indus valley, in Sind: Mohenjo-daro and Harappa. Here one sees the knowledge and foresightedness of the artisans in the selection, use of the material and their architectural skill.

Unfortunately the material and the technique used is not well documented. The information available is in excerpts. This book describes in part at least, some of these materials used and their mechanism of interaction. This is for a better understanding of the early development and use of building material which can be of immense help to all those who have an interest in and affection for the building whether ancient or modern the architect, the builder, the owner or occupier, the antiquarian and not least the archaeologist. It is of special interest for the restorer and conservators of historical buildings as it highlights the materials used in the ancient period. The field is so vast and the informations so scattered that the book cannot claim to be exhaustive but it will serve as the base for revival of the ancient technique and material, which were successfully used with profound durability. Most of the materials used were natural, locally available materials and had no adverse effect on the health of the builders. Thus this will help in solving the ecological problem in an environmentally friendly way.

January, 2003

R.S. Bisht
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PREFACE

When I read about the history of building materials most of the examples cited or which I came across were from Greece, Italy and Egypt. Very seldom I met some example from India. I knew that it is not correct. The other thing I marked was that the illustrations of the ancient buildings is done mostly from the architectural point of view, and not much is said about the materials used. At places some recipes were given. But the question occurs why those buildings made in the ancient period are so much durable where as the buildings made today with so much high and sophisticated technology and modern machinery fails much before the stipulated time. The ancient builders had learnt the technique and have developed the recipes by trials and errors. They had very much empirical knowledge but did not have scientific background to explain as to why or how a particular material interacts and impart certain properties to the concrete. Nevertheless they were confident of their knowledge. They use to say:

Go use this, it will work

Whereas what to-days practicing engineer says:

Go try this, it may work

Why “try and may”. This shows the uncertainty and lack of confidence or a type of fear. This has awakened the instinct inside me to somehow spread the information about the material and the knowledge of the ancient period. The task was not easy as there were not so much published materials available and being in Sweden it was very difficult to dig out what is even available. But I took it as a challenge and have decided first to test some of the organics used in the ancient period in India, which later was published in the international journals. This has brought very positive response, which has given me the internal happiness and energy to write a book about it.

I use to travel to India on vacation. But during this time I use to meet the old builders, archaeologist, architect's etc and talk to them about the materials used. These notes were developed and became the base for giving them the shape of a book.

The first part is a narration of the architecture of India in short. It is done to give an India about the style and the materials used in different periods. Though it is not so much new and specific as one meets the literature about the architecture of India but here some details about the materials used are emphasized. The second part exclusively deals with the materials, methods and application technique and the processes of their interaction. There is a separate chapter about the natural polymers, which were frequently used in the ancient period and are the key source for durability enhancement of the buildings. It has no parallel. It is a unique assemblage of informations and interpretation of the mechanisms involved. Apart

from the materials used in the ancient period in India, some compositions of the plasters and mortars are also described.

All this is not possible to do alone. I am very much thankful to the friends and colleagues specially Late Mr. Muni Singh and Mr. O.P. Agarwal, whom I met in 1978 for the first time, the then director of National Laboratory for Conservation of Cultural Property, Lucknow, India. Now Mr. Agarwal is associated with INTAC. From them I received very much inspiration to document the knowledge and techniques used successfully in India in the ancient period.

Recently during my visit to India I met Mr. R.S. Fonia, Superintending Archaeologist, AWES Lucknow circle who has invited me for the inauguration of world heritage week at the Residency. During this week, I discussed with the people involved in the restoration, historians and archaeologists, and was surprised to see their interest in this type of book. I am also very much thankful to my colleagues from the European Commission COST C5 Committee, Urban Heritage building maintenance for giving encouragement to produce this book. This has given me the extra energy to produce this book.

As mentioned earlier it is not an easy task specifically due to the not easy access to the literature. I do not know if I have done justice to all the techniques and materials used in the ancient period in India, but at the same time feel happy that at least something is documented which will give and spread the information about the art and science of the materials used in the ancient period in India. It will provide a possibility and opportunity particularly amongst the young engineers and architects to revive the old materials technology, which is unique and will keep up the old building materials tradition. It will help a lot in the restoration work specifically in producing the materials similar to the one used in the old buildings. It will increase the life span of the urban heritage—building maintenance. Some of the buildings stand even today in acceptable shape even after so many years speaks about their durability.

This book is written to counteract the fallacies and misconceptions that exist in the present day knowledge of practicing engineer who believes that the high strength material is the best to use for repairs and restoration without taking into consideration the strength status of the existing structure. This book is not expected to bring about dramatic changes in the construction industry but it is expected to help the people of different disciplines; Archaeologist, builders, restorers, historians etc, to better understand the traditional building materials.

January, 2003

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TERMINOLOGY AND DEFINITIONS

Accelerators : Chemical admixtures used to enhance the setting time of mortar or concrete are called accelerator.

Additives : These are the materials used to improve the properties of plasters, mortars and masonry both in the fresh as well as in hardened state. These can be of two types: 1) Chemical admixtures, 2) Mineral admixtures.

Admixtures Chemical : These can be both natural materials found in nature as were used in the ancient period and synthetic, man made in the industry. These are superplasticizers, air entraining agents, accelerators and retarders. These are mostly used as water reducing agents, and air entraining agents.

Admixtures Mineral : These are natural products like volcanic ashes or industrial by-products such as fly ash, condensed silica fume, blast furnace slag or colloidal silica, man made in the factory. These are pozzolanic materials. They interact with the calcium hydroxide and form calcium silicate hydrate. This produces material of higher strength and durability.

Agricultural Hydrate : It is relatively coarse, unrefined form of hydrated lime that is mainly used for neutralizing soil acidity and for purpose where high purity and uniformity are not required.

Air Entraining Agent : Chemical admixtures used to introduce extra air in the mortar or concrete mixture is known as air entraining agent. These are surface active agents, and are generally made of tensoids.

Air-slaked Lime : It contains various proportions of oxides, hydroxides, and carbonates of calcium and magnesium which result from excessive exposure of quick lime to air that vitiates its quality. It is partially or largely decomposed quick lime that has become hydrated and carbonated.

Autoclaved Lime : It represents the total free lime (CaO) content in a quick lime or hydrate and is the active constituent of a lime. It provides a means of evaluating the concentration of lime.

Bhatta : A type of kiln used for burning lime in India

Binder : A material used for binding the aggregates for making concrete. These can be; clays, lime, gypsum, pozzolanic cement or Portland cement.

Building Lime : It may be quick or hydrated lime (but usually connotes the latter), whose physical characteristics make it suitable for ordinary or special structural purposes.

Calcia : It is the chemical compound- calcium oxide (CaO).

Calcination : Burning of limestone to high temperature when it decomposes to calcium oxide, evolving carbon-dioxide gas.

Carbide Lime : It is a waste lime hydrate by-product from the generation of acetylene from calcium carbide and may occur as a wet sludge or dry powder of widely varying degree of purity and particle size. It is gray and possess the pungent odor of acetylene.

Carbonation : A process by which carbon dioxide interacts with lime to form calcium carbonate is called carbonation. Carbonation is most effective at 55% RH.

Chemical Lime : It is a quick or hydrated lime that is used for one or more of the many chemical and industrial applications. Usually it possesses high chemical purity.

Clay : The smallest fraction in the particulate breakdown of a soil (less than 0.002 mm diameter). It acts as the binder in earth based building materials.

Clay - sub soil : Soil contains clay and other materials. Clay is a part of the soil, amount of which varies from place to place. As such soil also contains bigger particles than the clay. It is a raw material for most types of earthen buildings.

Curing : The process of hardening and drying of mortars and masonry. Generally it is done under controlled conditions avoiding fast drying, which can lead to crack formation.

Dead Burnt Dolomite : It is a specially sintered or double burned form of dolomitic quicklime, which is further stabilized by the addition of iron, that is chemically inactive, and is employed primarily as a refractory for lining open-hearth steel furnaces.

Earth : It is a general term for ground. It may or may not be good for use in the building construction. It includes all type of inorganic and organic material. It is one of the five basic elements of Nature; Earth, Sky, Water, Fire and Air. So it should not be confused with the clay and soil.

False Set : See setting time.

Flash Set : See setting time.

Fat Lime : It is a pure lime (quick or hydrated), distinguishing it from an impure or hydraulic lime. it is also used to denote a lime hydrate that yields a plastic putty for structural purposes.

Filleting : It is also called as edging of broken ends of plastering. Often in the ancient monuments, due to weather action the plastering of surface is damaged. The mortar used for edging generally provides high strength. The mortars used contain ingredients like broken brick pieces, stones, coarse sand, gravel, small *kankar* nodules.

Finishing Lime : It is a type of refined hydrated lime, milled in such a manner that it is suitable for plastering, particularly the finish coat. Putty derived from this hydrate has very high plasticity.

Flocculation and Agglomeration : The addition of lime to a fine grained soil causes flocculation and agglomeration of the clay particles. As a result, there is an apparent change in texture with clay particles "clumping" together into a larger sized "aggregate".

Fluxing Lime : It is lump or pebble quicklime used for fluxing in steel manufacture- or the term may be applied more broadly to include fluxing of non ferrous metals and glass. It is a type of chemical lime.

Gauging : Addition of material to the mortar to obtain desired working properties.

Geru : Red Ochra, generally used as red paint.

Ground Burnt Lime : It refers to ground quick lime used for agriculture purposes.

Grouting : Injection of grout which consist of a binder, fine aggregate as filler, water and some additives. This is used to repair the internal damages and thus to strengthen the structure.

Hard Burnt Lime : It is the quick lime that is calcined at high temperature and is generally characterized by relatively high density and moderate to low chemical reactivity.

Hardening : The process during which the material gets hard, achieves strength, and is no longer elastic to be molded. see curing.

Hydrated Lime : It is in the form of dry powder obtained by hydrating quick lime with enough water to satisfy its chemical affinity, forming a hydroxide due to its chemically combined water. It may be high calcium, magnesium, dolomitic, or hydraulic.

Hydraulic Lime : It is chemically impure form of lime with hydraulic properties of varying extent that possesses appreciable amounts of silica, alumina, and usually some iron, chemically combined with much of the lime. It is employed solely for structural purposes.

Hydrophobic : A material which resists water penetration is called hydrophobic material.

Kankar : It is a special type of calcined clay for making red lime, which has very high hydraulic property.

Kankar Lime : The lime from the calcined clay. It is also known as red lime. It is very much used in India, specially in imitating the red marble.

Knocking up : The reworking of a mortar mixture in order to regain plasticity before use.

Laitence : Thin layer of binder (lime or cement) particles on the surface of mortar, generally caused by over-working or by using the mortar too wet.

Lean Lime : Limes which contain less than 90% calcium oxide are known as Lean lime. These are also known as poor lime.

Lime : It is general term which denotes only a burned form of lime, usually quick lime, but may also refer to hydrated or hydraulic lime. It may be calcitic, magnesian, or dolomitic. It does not apply to limestone or any carbonate form of lime.

Lime Putty : It is a form of lime hydrate in a wet, plastic paste form, containing free water.

Lime Slurry : It is a form of lime hydrate in aqueous suspension that contains considerable free water.

Limewash : Limewash is a dispersion of calcium hydroxide particles in an aqueous solution of approx. 1 g/l Ca(OH)_2 . It is made by putting lime in water for a long time. Lime putty which has been stored for long time with a water content of 52% by mass can be used. It is thinned with water to the suitable concentrations.

Limewater : Limewater is made by adding lime to water and stirring. Allow the lime to settle so forming a saturated solution. This is used by a soft brush over the limestone masonry.

Lump of Lime : It is a physical shape of quick lime, derived from the kiln.

Magnesia : It is the chemical name of magnesium oxide MgO , that is an important constituent in dolomitic and magnesium limes.

Masons Lime : It is a dilute lime hydrate in aqueous suspension and is of milk consistency.

Micrograph : Photograph of the microstructure of masonry, concrete or any other material taken on the microscope.

Microstructure : It constitutes the nature of the solid body and that of the non-solid portion, that is, porous structure. Microstructure feature depend on many factors, such as the physical and chemical nature of the cement, type and amount of chemical admixture added to it, temperature and period of hydration and the initial water to cement ratio.

Mud : It is a workable mixture of clay soil and water. It may also contain fine aggregates like sand or stone dust.

Natural Polymer : Chemicals used as additives in the plasters, mortars and masonry to improve their rheology in the fresh state and mechanical, and durability properties in the hardened state. These are mostly natural materials found in nature. These are also known by the name organics.

Non- hydraulic lime : Lime which hardens only on absorption of carbon dioxide and drying. It does not harden under water.

Organics : Chemicals used as additives in the plasters, mortars and masonry to improve their mechanical, and durability properties. These are mostly natural materials found in nature. These are also known by the name natural polymers.

Pebble Lime : It is a physical shape of quick lime.

Plasticity : It is a property of mortar showing the workability and cohesiveness.

Permeability : The ratio of movement of water through concrete under a pressure gradient is termed as permeability.

Pointing : Filling the joints in brick work or masonry with mortar is known as pointing. This is done to enhance the strength of the structure. Besides, it also prevents entering of dust and rain water into the structure which helps in growth of vegetation damaging the structure.

Porosity : Amount of voids in the mass of material. It is of two types: Open and closed porosity. Open porosity relates to the pores, which can be filled up with fluid. Whereas the closed porosity relates to the pores, which are sealed and thus can not be filled up.

Pozzolanic Material : A material, which reacts with calcium hydroxide or alkalis in the binder system and produces the compounds, which help in increasing the strength of concrete and durability properties (see admixtures mineral).

Pressure Hydrate : It is synonymous to autoclaved lime and is the most common variety of ASTM designated Type S hydrated lime.

Quick Lime : It is calcium oxide formed by calcining limestone so that carbon dioxide is liberated. It may be high calcium, magnesium, or dolomitic and of varying degrees of chemical purity.

Rakhi : It is the Indian name for Pulverized Fuel Ash, PFA, from thermal power stations.

Ramraj : Yellow Ochra. Generally used as yellow paint.

Red Lime : Lime, which is produced by calcining special clay known as *Kankar*. This clay contains high amount of iron which produces red color on calcination.

Refractory Lime : It synonymous to dead burned dolomite, an unreactive dolomitic quick lime, stabilized with iron, that is used primarily for lining refractories of open hearth steel furnaces.

Rendering : It entails cutting off all the damaged masonry and replacing it with mortar to provide a fully bonded surfacing for preserving the structure against further deterioration.

Retarders : Chemical admixtures used to delay the setting time of mortars and concrete are known as retarders .

Roman Cement : It is synonymous to lime pozzolanic cement. It is impure and is highly hydraulic type.

Roman Lime : It is synonymous to hydraulic lime, but is impure and is highly hydraulic type.

Run-of-Kiln Quick Lime : It is unclassified quick lime as discharged from a kiln.

Sedimentation : Settlement, the sinking of soil or mineral grains to the bottom of the water which contains them. Larger particles settle faster than the smaller particles of the same shape.

Seepage : Percolation of small quantities of water through the soil or a wall. Seepage loss from a canal or reservoir is expressed as a depth over the surface or over the wetted perimeter per unit of time. Inward seepage is called influent seepage and outward seepage is called effluent seepage.

Segregation : Large stones drop farther in the same conditions than the small ones. concrete can segregate when poured down a chute, dropped from a height, or punned too much or too little. Segregation is a separation of the concrete into over-sanded and under sanded masses. It greatly weakens the concrete, and causes honey-combing, but can be prevented by correct grading, careful placing or punning or vibration.

Self Burned Lime : It is quick lime that is calcined at relatively low temperature. It is characterized by high porosity and chemical reactivity.

Setting Time : The time taken for a binder; lime, cement etc. to stiffen is termed as setting time. The initial setting time when the paste starts stiffening and can no longer be properly handled and placed. The final setting time corresponds to the stage where hardening begins. This is measured by Vicat needle-Concrete made with the binder containing gypsum also exhibits false set or flash set when it looks like stiffened concrete. Stiffening occurs due to the presence of partially dehydrated gypsum. Workability is restored by remixing.

Silt : Finely divided mineral particles, usually less than 75 μm diameter. Smallest sizes (below 2 μm) will stay in suspension.

Slaking : It is the reaction of quick lime obtained by calcining limestone with water. The reaction is exothermic. The lime produced is known as slaked lime.

Slaked Lime : It is hydrated form of lime, as a dry powder, putty or aqueous suspension.

Slurry : A thick but fluid mixture of fine dry powder in water.

Soil Cement : The soil cement contains a significant amount of alkalis (Na_2O , K_2O from 3-20%) and components determining their bonding properties mainly caustic alkalis (ROH). The oxides of alkaline soils do not exist in the system or sometimes they are added in the form of or together with metallurgy slag and the existing calcium binders. In the first case the binder is alkaline, structure formation bonds are supplied only by alkaline alumina-silicate types, sodium or sodium potassium zeolite, mica or hydrous mica. In the second case the binders are alkaline soils having a bond of C-S-H gel and consisting of above mentioned alkalis or a combination of alkali-alkaline soil alumino-silicates.

Spray Lime : It is specially milled dry hydrated lime of very fine particle size so that at least 98% passing through a No. 325 mesh screen.

Stabilization of Clay : Stabilization of clay generally means increasing its durability. It is accomplished by the addition natural or synthetic chemicals aided by the mechanical treatment.

Stabilization of Lime : Lime base building materials are not very durable. Their durability is increased by stabilizing them The stabilization is done by physical and chemical treatment. Physical treatment is done by slaking lime for longer time. Chemical stabilization is done by the addition of

organic or inorganic materials. The inorganic materials used for stabilization are known as pozzolanic materials. The other type of stabilizers used are organic materials, also known as natural polymers.

Strength of Materials : The calculation of stresses due to tension, compression, shear force, bending torsion, and in any of these stresses combined.

Stress : The force on a member divided by the area which carries the force, usually expressed in pounds per square inch, Kpf per square cm.

Surkhi : It is fine milled powder from the red bricks, which is used as pozzolanic material in India.

Tamper : A screed board, sometimes with a mechanical vibrator on it.

Tampering : The process of compaction with vibrators or screed board.

Temperature Gradient : A change in temperature per unit length.

Thixotropy : The property possessed by some gels of becoming fluid when stirred and of returning to the jelly state when stirring ceases. In drilling fluids this is a most important property, which enables them to hold large rock chippings suspended for indefinite periods when drilling ceases for any reason.

Thixotropic Fluids : Clays, which are thixotropic show this effect by a weakening when they are remolded and an increase in strength when they are allowed to stand undisturbed. Thixotropic paints do not always have good flow but pigments settles very slowly in them and they do not run off.

Type S Hydrated Lime : It is also called special hydrated lime. It is an ASTM designation to distinguish a structural hydrate from a normal hydrated lime, designation Type N, that possesses specified plasticity and gradation requirements. It may be dolomite or high calcium and is more precisely milled than Type N hydrates.

Water Repellency : The property of resistance against water penetration. It is synonymous to hydrophobicity.

Water Retaining Additives : The chemical additives which helps in keeping the water in the plasters, mortars or masonry. These are generally cellulose derivatives. The mixture does not dry fast by their addition and thus controls the drying shrinkage.

Whitewash : It is synonymous to milk of lime, a dilute lime hydrate suspension.

Workability : the property of plaster, mortar or concrete which provides ease of working, homogeneity with which it can be mixed compacted and finished.

Zeolite : Zeolite are alkaline sodium, aluminium silicon hydrates. These are found in nature and have composition : $R_2O \cdot RO \cdot R_2O_3 \cdot (2-4)SiO_2 \cdot nH_2O$. These are the major components of Soil cement, and one of the structural forming component in the concrete is the amorphous-crypto-crystalline zeolite.

LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations

ASTM	American Standard of Test Methods
BS	British Standard of Test Methods
DIN	German Standard of Test Methods
GOST	Russian Standard of Test Methods
ISI	Indian Standard of Test Methods
ISO	European Standard of Test Methods
SS	Swedish Standard of Test methods
OPC	Ordinary Portland Cement
PFA	Pulverized Fuel Ash
BFS	Blast Furnace Slag
CSF	Condensed Silica Fume

Symbols

C	CaO	Calcium oxide
A	Al_2O_3	Aluminium oxide
S	CaSO_4	Calcium sulphate
H	H_2O	Water
F	Fe_2O_3	Iron (III) oxide
CH	Ca(OH)_2	Calcium hydroxide
CS	CaO.SiO_2	Calcium silicate
CSH	$\text{CaO.SiO}_2.\text{H}_2\text{O}$	Calcium silicate hydrate: Tobermorite
C_2S	CaO.2SiO_2	Di-calcium silicate
C_3S	CaO.3SiO_2	Tri-calcium silicate
C_3A	$\text{CaO.3Al}_2\text{O}_3$	Tri calcium aluminate
C_4AF	$4\text{CaO.Al}_2\text{O}_3.\text{Fe}_2\text{O}_3$	Tetra-calcium aluminoferrite
$\text{C}_6\text{AS}_3.\text{H}_{32}$		Ettringite
$\text{K}_2\text{O.Al}_2\text{O}_3.6\text{SiO}_2$		Potassium alumina silicate (Potassium feldspar)
CaCO_3		Calcium carbonate (Calcite, Vaterite, aragonite)
$\text{Al}_2\text{O}_3, \text{Fe}_2\text{O}_3$		Amphoteric oxides
$\text{NH}_3(\text{gas})$		Ammonia
$\text{Na}_2\text{O.Al}_2\text{O}_3.4\text{SiO}_2.2\text{H}_2\text{O}$		Analcime
CaCl_2		Calcium chloride
KOH		Caustic soda

H_2CO_3	Carbonic acid
Cl^-	Chloride
HCl(aq.)	Hydrochloric acid
NO_2	Nitrogen oxide
NO_3^-	Nitrate
$\text{HNO}_3\text{(aq.)}$	Nitric acid
NaOH	Sodium hydroxide
$\text{SO}_2\text{(g)}$	Sulphur dioxide
SO_4^{2-}	Sulphate
H_2SO_4	Sulphuric acid
NaCl	Sodium chloride
R_2O RO R_2O_3 (2-4) SiO_2	Natural oxides
$n\text{H}_2\text{O}$	

CONVERSION FACTORS

	FROM	TO	DIVIDED BY
LENGTH	Centimeters	Microns	0.0001
	Inches	Centimeters	0.3937
	Feet	Meters	3.28083
	Miles (English)	Kilometers	0.62137
AREA	Square inches	Square centimeters	0.1550
	Square feet	Acres	43560
	Acres	Hectares	2.471044
	Square feet	Hectares	107639
VOLUME	Cubic yards	Cubic meter	1.3070
	Gallons (US)	Liters	0.26418
	Cubic feet	Gallons (US)	1.3368
	Gallon (US)	Gallons(British)	1.20094
WEIGHT	Pounds	Kilogram	2.204622
	Tons (short)	Metric tons	1.10231
	Tons (long)	Metric tons	0.98421
	Barrels (376 pounds)	Metric tons	5.8633
	Tons (short)	Tons (long)	1.12
	Barrels (376 pounds)	Tons (long)	5.957
	Barrels (376 pounds)	Tons(short)	5.3191
	Pounds per square inch	Kilogram per square centimeter	14.2233
TEMPERATURE	Degree Fahrenheit	Degrees centigrade	(°C x 1.8 + 32)
HEAT	B.t.u	Calories (kilogram)	3.96753
POWER	B.t.u	Kilowatt hours	3413.44

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PART I: ARCHITECTURE

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INTRODUCTION

Today one come-across and reads about the developments of new building materials particularly the chemical admixtures both organic and inorganic. But the question arises

*"If really these are the new materials
which were never ever known to the
building people?"*

The answer is no.

The chemical admixtures both organic and inorganic were used in the ancient period. The organic admixtures were the natural mostly the agro-products and the inorganic were the natural and artificial pozzolana. In a way it is no exaggeration to say that the roots of chemical admixture addition in the building materials are from the ancient period. The difference is that in the ancient period the materials used were in the natural form whereas today man made materials are used. Being the natural products, those materials in the ancient period had natural balance and were stable in a wider range of environmental conditions whereas the synthetic materials are stable within the specified conditions. This may be one of the reasons, why the ancient buildings are in good shape even today after so many harsh years of exposure.

The ancient builders had immense knowledge about the materials and technique, which they have acquired by trial and error. They had empirical knowledge with out proper scientific explanation. Besides, this being their living bread these artisans were scared to disclose the materials and technique used. (This is one of the reasons why there is no documentation and poor literature on the ancient building materials, and the technology which was, so successfully used in the ancient period is successively disappearing. This is a matter of grave concern. At the same time it is very interesting to dig out the information about the materials from FDIC literature, historical books or by talking to the people particularly in the villages who still know and keep up the traditional building technique.

— In this part information's obtained from different sources have been compiled about the binders: clay, lime, pozzolana etc, about the organics: natural polymers used in the ancient period and have been illustrated with the methods used for producing the plasters and mortars. Preparation of different natural polymers and the mechanisms involved in their interaction in order to enhance the durability properties is also described. This is not

only the collection of information's, it deals in a very systematic way with (a) the materials: binder systems, aggregates, natural polymers, (b), selection of land and rule for designing the house, (c) Technique of producing the material and its application technique, and finally (d) there are some results of the studies done on the ancient materials, which are published in the international journals. Apart from the natural polymers used in India, these as were used in the other part of the world are also described.

The aim of this part is to have a better understanding of the early development and use of building materials, which can be of immense help to all those who have an interest in and affection for the building whether ancient or modern, the architect, the builder, the owner or occupier, the antiquarian and not least the archaeologist. It is of special interest for the restorer and conservators of historical buildings as it highlights the materials used in the ancient period. The field is so vast and the information's so scattered that the book cannot claim to be exhaustive but it will serve as the base for revival of the ancient technique and material, which were successfully used with profound durability.

PART I

ARCHITECTURE

1

1. INTRODUCTION

The history of architecture and so the building material in India is not a continuous story. In India as in other countries, culture and architecture are connected with political power, although religion was the main inspiration behind the architectural achievements, and was dominating the political order. No temples were built by Muslims, no mosques by Christians and no cathedrals by Hindus. The correlation is clearly seen in India. The political history of the country can be divided into three separate cycles. Accordingly three distinct motivations and styles of buildings were built in three successive ages.

1.1 Indo-Aryan, Indo-Islamic and Indo-British Period

The beginning of the first cycle cannot be precisely mentioned but it lasted until the end of the 12th century of the Christian era. The country was ruled and dominated by the people known as Hindus. These people brought into existence the ancient Indian civilization in which there were two religious sects-Brahmanism, popularly called Hinduism, and Buddhism. The second cycle started from the beginning of the 13th century and lasted until the middle of the 18th century. During this period northern India was ruled by Muslims, who came from Central Asia; from Persia and from Afghanistan. Later, parts of south India were also ruled by them. These Muslims created an Independent Colonial order for themselves in India. The third cycle was the period of British rule from 1858 to 1947. The three distinct cultures created by the three political cycles can be classified as Indo-Aryan, Indo-Islamic and Indo-British.

The Indo-Aryan culture, irrespective of the foreign origins of the people, became and remained self-contained and wholly Indian. The affiliation of the Indo-Islamic culture was with the middle east; it was in fact only a regional form of the culture of the entire Islamic world. The third political cycle bears witness to the emergency of a culture with the impact of western civilization. Accordingly during the first period Hindu and Buddhist monuments were made, during the second Islamic monuments and in the third western style buildings were constructed.

The political bearing of Indian architecture is also illustrated by its expansion overseas. Hinduism, Buddhism and the general culture, specially from the south, spread to Burma, Indonesia, and Indo-China. These elements created not only a colonial form of Indian civilization in these regions, but also found an architectural embodiment which was no less impressive than in India. Indian sculpture too was an accomplishment of this extension of art.

Indian political history made yet another destructive impact on her architecture. It is responsible for a completely one-sided view of ancient Indian architecture, in which the importance of the south is emphasized at the cost of the north. The impression is that south India is the land of temples and is different from the gangetic basin in material culture. This is due to the historical fact that the temples of the gangetic basin were destroyed by the Muslims, who razed to the ground all Hindu temples wherever they found them, except during the short period of Akbar 1556-1605. Even before the establishment of Muslim power in India, in the 10th century, Sultan Mahmud of Ghazni had sacked most of the great religious centers in northern India in the course of his repeated invasions. As a result of this widespread destruction, Hindu and Buddhist monuments survived in northern India only in those regions into which Muslims did not penetrate - Bundel Khand, Orissa, Rajputana, Nepal and Himalayan foothills. In the northern plain, temples began to rebuild only in the 18th century, when the Marathas became dominant.

1.2 Periods of Indian Art

All the surviving examples of ancient Indian architecture are religious monuments. No residential buildings or any other form of secular architecture have survived in the south, the elaborate palace complex of the Hindu Kingdom of Vijanagara was sacked by the Muslims after their conquest of the city in 1565. But Sanskrit literature contain numerous references to splendid mansions and palaces which rose to the sky and there can be no doubt that the domestic architecture of ancient India was elaborate. The periods of Indian art is given below in the chronological order:

Indus valley culture	c. 2500-1500 B.C
Pre-Maurian Art	c. 650-325 B.C
Maurya Sculpture	c. 325-185 B.C

Sunga Sculptures	c.185-72 B.C
Satvahan period	200 B.C-200 A.D
Kushan Gandhar Art	c.1 A.D-176 A.D
Gupta Art	c. 320-600 A.D
Chalukyan Art	550-973 A.D
Pallav Art	600-750 A.D
The Pala School	700-1200 A.D
The Orissa School	c.700-1200 A.D
Khajuraho Temples	950-1050 A.D
Hoysala Art	1111-1318 A.D
Other Medieval Monuments	c.1000-1600 A.D
Indo-Islamic Monuments	c.1200-1700 A.D
Portuguese, French and British	1526-1857 A.D

2. INDO-ARYAN PERIOD

2.1 Prehistory and Proto-History-Indus Valley Civilization

The Indus Civilization of the bronze age is among the four widely known civilization of the world. It has variously been called the “Harappan Civilization” or the “Indus-Saraswati Civilization. It was a contemporary of the Egyptian and Mesopotamian civilizations, and yet different from them in several important respects, such as the system of writing, town planning and religious beliefs. The civilization arose from people who, around 5000 B.C., migrated from the eastern foothills of Baluchistan to the river valleys of Indus and the Saraswati. The remains of this undoubtedly great civilization were first discovered in 1921-22, when Harappa was excavated, followed by Mohenjodaro a year later: Since then, over 1400 sites belonging to this civilization have been discovered in India and Pakistan, of these, around two dozen have been excavated. Indian Archaeological survey of India excavated several important sites, such as Lothal (S.R.Rao), Kalibanga (B.B. Lal and B.K. Thaper), Surkotada (J.P.Joshi), Banawali and Dholavira (R.S.Bisht) and Rakhigarhi (Amarendranath).

The Harappan civilization extended much beyond the basins of these two rivers as well. It covers a distance of 160 km from the north to the south, and around the same distance from the east to the west, covering an area larger than twice of that occupied by mesopotamian and Egyptian civilizations put together.

The Harappan civilization is divided broadly into three phases: the Early phase (3500-2600 B.C); the Mature phase (2600-200 B.C), and the late phase (2000 B.C -1500 B.C).

The Harappan civilization grew step by step in time and space, from the village stage to the township stage and finally to the city stage. The Harappan civilization is known for its well-planned cities, the like of which

no other contemporary civilization produced. While in Egypt and Mesopotamia, only the ruling and religious elite had well-built houses, and the common men lived in huts. In the Harappan towns even the commoners lived in well-built houses. Like the other civilizations, the Indus Valley civilization seems to have grown from the skillful utilization of the fertile river valley.

Although each city was planned differently, a city was broadly divided into two major sectors- the so called "citadel"; meant for the elite, and the other, the lower town" for the common men. The lower town contained sectors for specialized crafts, for shops and *bazars*, for social gathering, etc. The citadel did not necessarily have a defensive structure or role-it is so called because of the magnificent building it contained. Some ready examples are the series of platforms, with fire altars, at Kalibangan, the Great Bath at Mohenjodaro, the "Warehouse" at "Lothal" and "Granaries" at Harappa and Mohenjodaro, public buildings such as pillared Halls at Mohenjodaro and Dholavira, the "rangshala" or stadium at Dholavira; and special purpose structure as the "Dockyard" at Lothal".

The Harappan cities are characterized by their neat roads and lanes, laid out with geometric precision, and usually crossing each other at right angles to form a "grid" or "chessboard pattern". Blocks of houses, some with open courtyards had furnished toilets, kitchens, living rooms, and a few had staircases leading to the roof or upper storey. Mostly, the Harappan settlements are secured by a defensive wall with gateways.

Since the independence, excavation work has been going on in India and as a result, the entire position regarding the extent, culture contents, regional variations of the Indus valley civilization has substantially changed [Joshi, 1994]. The distribution of the Harappan settlements covers a vast area which runs from Desalpur and Dholavira (Gujarat) in the west, Manda in Jammu and Kashmir (J & K) in the north, Daimabad (Maharashtra) in south and Hulas (Uttar Pradesh) in the east. Among the excavated sites in India; Kalibangan, Lothal, Surkotada, Banawali, Dholavira, Kuntasi, Daimabad, Hulas and Manda are of potential importance for throwing fresh light on the cultural and to some extent to its origin in the antecedent cultures. The excavated sites are shown in map (Figure 2.1).

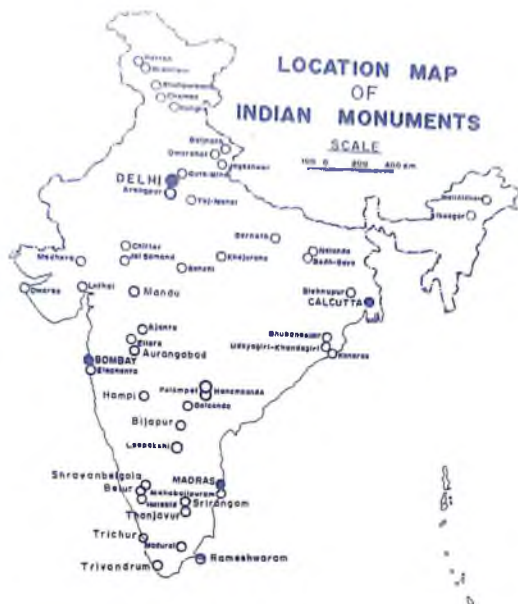


Figure 2.1 : Map of India, Position of different excavations.

2.1.1 Kalibangan

Kalibangan lies on the left bank of the river Ghaggara (ancient Sarasvati) in the northern part of Rajasthan. It comprises of two mounds, the smaller one to the west and the larger one to the east, recalling identical disposition at Mohenjo-daro. The excavation brought to light a gridiron lay out of the Harappan metropolis. Another significant evidence is in the form of a non-Harappan settlement, underlying the Harappan citadel. The pre-Harappan settlement, designed like a parallelogram, was surrounded by a fortification made of mud bricks. The houses within the walled area were also of mud bricks (Figures 2.2 and 2.3). The distinctive trait of this period was the pottery which was significantly different from that of the succeeding Harappans. An outstanding discovery of the excavation, however, was a ploughed field showing a grid of furrows. It was situated to the south east of the settlement outside the town wall. This is perhaps, the earliest ploughed field excavated so far.

During the Harappan period, the structural pattern of the settlement was changed. There were now two distinct parts: the citadel on the west and the lower town on the east. The former was situated atop the remains of the preceding occupation to gain an eminence over the lower town which was laid out on the natural plain towards the east. The citadel complex was a fortified parallelogram, consisting of two equal but separately patterned parts. The fortifications were built throughout of mud bricks.



Figure 2.2 : Kalibanga; Pre-Harappan Structures.



Figure 2.3: Kalibangan; Street.

The southern half of the citadel contained some five to six massive platforms, some of which may have been used for religious or ritual purposes. The northern half of the citadel contained residential buildings of elite. The lower town was also fortified. Within the walled area was a gridiron plan of streets running north-south and east west, dividing the area into blocks. The houses were built of mud bricks, baked bricks being confined to drains, wells, sills etc.

Besides the above two principal parts of the metropolis, there was also a third one, situated upwards of 80 m east of the lower town. It consisted of a modest structure, containing four to five "fire altars" and as such could have been used for ritual purposes.

2.1.2 Banawali

The ancient site at Banawali, district Hissar, Haryana, is located on the right bank of the river Sarasvati, which does not exist today. The antiquarian remains are found spread over an area of about 400 m square and attain a height of about 9 to 10 meters above the surrounding ground level. The excavations at this site have yielded the remains of pre-, intermediate, mature and post Harappan cultures (Figure 2.4).

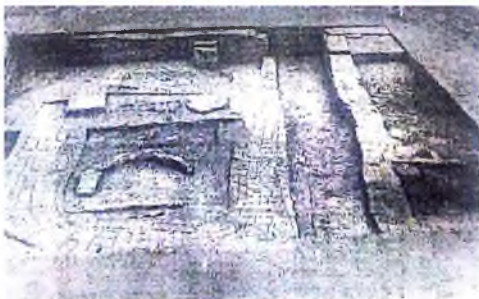


Figure 2.4 : Banawali; Apsidal structure with a fireplace.

Period I (Pre-Harappan/Kalibangan culture); 3.20 m of regular occupational debris, has revealed three sub-phases. The first two phases represent geographical extension of the pre-Harappan culture found in Period I of Kalibangan. The settlement was a fortified one and mud bricks of standard sizes set in mud mortar were the principal building material. The bricks were in the ratio 3:2:1. In pottery, all the six factories of

Kalibangan I together with form, surface treatment and decoration are duly present.

Period IA (Pre-defense phase), is represented by an average deposit of 0.60 m with one structural phase, although the possibility of the second one cannot be ruled out. During this period, it was an open settlement having no circumvolution. Comparatively, the pottery, more particularly that of fabric A is finer in quality in terms of clay, baking, lightness, surface treatment and painted motifs. The molded bricks set in mud mortar were the usual building material. A solitary fired brick structure resting right upon the natural soil also belongs to this period.

Period IB (Defense phase), having 1.60 m deposit, is represented by two major constructional phases of defensive wall and five phases of houses. Originally, the fortification wall was 1.40 m wide with no tapering on either side. Due to faulty construction, it soon started developing signs of tilting and cleavage and thus necessitating its augmentation by raising ancillary dwarf wall along the inner side. Since this measure did not seem to withstood as it was further damaged from the outside by water action, the people rebuilt it into a massive fortification wall of which the extant width has been noticed to be 2.50 to 3.50 m (7.5 to 10.5 feet) because some portion of it has been chiseled out or sliced away slightly obliquely from outside by the builders of the succeeding period. It is interesting to note that the defensive wall looks like a horse shoe following the existing natural elevation. The longer axis of the settlement most probably lay from east to west. Although, at the initial stage, the pre-Harappans did not leave any space between the wall and the houses built inside, but after sometime, they always left enough room for a narrow collateral passage.

Period IC (Transitional Phase), is denoted by a 0.90 to 1.20 m (2.7 to 3.6 feet) thick deposit and is marked by drastic and diagnostic changes in architecture, planning and antiquities in an otherwise continuing ceramic milieu of the preceding sub-period. The entire settlement was planned and constructed de- novo. The fortification of the previous period was externally chiseled or partially sliced away from the outside in order to raise another massive wall against it and converted the walled area of the preceding period into a citadel, and the lower town was laid out continuously towards the east, north, and west. The bricks were molded into new measurements giving the ratio of 4:2:1. At several places, it was observed that the orientation of houses of the preceding sub-periods was modified or changed

altogether. It was also firmly confirmed that the radial arrangement of streets of the lower division came into being due to the curvilinear nature of the antecedent fortification.

Period II (Harappan culture), it belonged to Harappan. It is an unique example of the town planning which consisted of a binocular settlement enclosed within a general fortification. The two principal divisions were an acropolis or citadel on a higher level and a lower town, segregated from the former, by massive wall and enclosed by a general fortification. The bipartite wall, primarily meant for fortifying the acropolis, started betraying quite an unusual configuration on the north-east. The later work revealed that the Harappans in fact inherited the planning from their predecessors of period IC.

Period III (Post-Harappan culture), It arrives at site after desertion. The new comers settled to the east of the older site.

On the older mound, they dug up only large and deep pits to dump the broken pottery or refuse, or for making kilns for baking pottery or clay nodules. Bricks as building material had gone out of use. Instead, the house walls were made of well levitated fine earth. The sides were usually plastered over with the self-same earth but often mixed with cow-dung or husk or both. Even the house floors were made of the same earth successively.

2.1.3 Manda

It is situated 28 km west of Jammu on the right bank of the river Chenab, in the foot hill of the Sivalik. It represents the northernmost identified site of the *Harappan culture*. The excavations at the site yielded a three fold sequence of cultures with two sub-periods in Period I. In sub-Period 1A, the site was under occupation by the Harappans, as represented by the finds of some typical Indus pottery, triangular terracotta cakes and a double-spiral headed copper pin of West Asian type. From the unstratified levels, an unfinished seal-stone testifying to the Harappan affiliation of the site, was also obtained. In sub-Period 1B, Harappan pottery continues alongwith the appearance of the Grey ware.

2.1.4 Dholavira

Dholavira, district Kutch, Gujrat, has emerged as a major Harappan city, remarkable for its exquisite planning, monumental structures, aesthetic architecture and wonderful water-management system. An inscription of ten large sized signs of Harappan script are found in Dholavira-the oldest

sign-board of the world. As is revealed by the archeological survey of India [Bisht, 1999] there were seven cultural stages. The first settlers came well equipped with advanced ceramic techniques, copper working, lithic industry, bead making, stone dressing and with definitive principles of town planning and architecture. They constructed a formidable fortification (as thick as about 11 meters at the base) around the settlement. The houses were made of molded mud bricks of standardized sizes providing the ratio 4:2:1.



Figure 2.5 : Dholavira: North gate [ASI].



Figure 2.6 : Dholavira: East gate , Rock cut water reservoir at Dholavira [ASI].

In stage II, the fortification wall was widened. This was done by adding a 2.80 m thick brick masonry wall from the inner side of the pre-existing defensive wall. The face of it was plastered over with fine paste of white and pink clays at least thirteen times. The settlement extended to the north. While the cultural objects of the earlier stage remained in use, there is observed an increase in ceramic forms and decoration and in the quantity of minor antiquities. Stage I and II show temporal and cultural affinity with Amri IIB, Nausharo ID and Kot-Diji I. A picture of a rapidly growing society is evident. North gate and east gate are shown in the Figures 2.5 and 2.6.

Stage III is a very creative period when small settlements grew into large town having two fortified major divisions in addition to annexes and water reservoirs-all within peripheral wall. The existing fortified settlement was, in fact, made into citadel and another fortified sub-division was added to it in the west. These two sub-divisions have been designated as castle and belly respectively. During the end of this stage the entire settlement witnessed natural catastrophe. Large scale repairs were made and significant changes were done in the town planning.

In the stage IV among most impressive items are the elements of functional pillars and free standing columns made out of locally available limestone.

The stage V is characterized by the general decline particularly in the maintenance of the city. It is more vividly reflected in the citadel. The other items such as pottery, seals, weights, etc, continued in use.

This stage was followed by a temporary desertion of the site, perhaps not lasting more than a few decades before the Stage VI ushered in.

Stage VI presents a state of transformed Harappa culture which is so widely distributed in Gujrat. New ceramic traditions coming from the sides of Sind, Rajasthan and other parts of Gujrat made appearance. The one time city shrank into smaller town which became confined to the citadel and the southern margin of the middle town where they delimited it by raising a wall of entirely different workmanship. It is surmised that having lived there for about a century, the late Harappans of Stage VI abandoned the settlement.

The desertion that followed was certainly a longer one, but its time can not be ascertained. The new comers of **Stage VII** had forgotten the classical Harappan fabrics, shapes and designs. The new comers built their houses in an entirely new form that was circular. All the urban attributes became conspicuous by their absence.

2.1.5 Water tank

In its heyday, the entire city might have looked like a lake-city or a *Jal Durga* (water fort). The tank area was very big approximately 750 m in length along the southern and northern margins, while the width varied from 70 to 80 m. In the west, the tank area was about 590 m. In the southeastern area, for example, the reservoir covered about 5 ha, the largest within the wall area. The walls acted as effective *bunds*. Both faces of the wall were plastered with fairly water repelling sticky clay. Certain areas mostly on the exterior face, were veneered with hammer-dressed stones. As the city was on the slope *bunds* were constructed across the width of the tanks to reduce the pressure of the stored water body on the city walls. In the times of rainfall, they enabled the water to get stored in selected tanks instead of being spread out over a large area and reduced quickly by evaporation and seepage. In the area designated as the citadel, an interesting network of drains, both small and large, was discovered. Most of the drains intersect each other and ultimately link up with an arterial drain.

The entire drainage system could have been set up to assiduously conserve every drop of rain water that fell in the city. The water must have been a treasured commodity in an area lacking in the source of surface water.

2.1.6 Lothal

Lothal is situated 80 km south west of Ahmedabad, Gujrat, on the coastal flats at the head of the Gulf of Cambay. It was subjected to frequent floods as it was close to the junction of Sabarmati and Bhogavo rivers. Nevertheless it has the advantage of transportation through both the rivers. Due to its being a low natural mound, it had been reinforced with mud and mud bricks against the annual floods on more than one occasion. Five phases of occupation was observed here. Out of this four have been mature Harappan culture. The settlement was rectangular on plan and consisted of two parts: citadel and lower town. The citadel or acropolis was located in the south-western part and was distinguished by its prominence being built upon mud and mud brick platforms. Of the structures, exposed within the citadel, the warehouse is, perhaps, more noteworthy. Built on a 4.0 m in high podium, it had 64 blocks of mud bricks, serving as a base for a wooden superstructure, which got burnt. Burnt clay ceilings of normal Indus type presumably fallen from the stored bales, had been recovered from the ducts between the blocks. The lower town contained, apart from the residential sectors, a bazaar, and industrial area. The most individualistic structure brought to light by the

excavation was an oblong basin measuring 214 x 36 m, riveted on all sides with baked brick walls. It was furnished with a sluice gate and an inlet (Figure 2.7). The structure is thought to have been a dock for berthing the ships. The occurrence of a circular seal of Persian Gulf style at the site points to the existence of maritime trade with Gulf region.



Figure 2.7 : Lothal: Dockyard.

2.1.7 Bhagwanpura

Bhagwanpura in the district Kurukshetra, showed two-fold cultural sequence designated as sub-period IA and IB in a deposit of 3.20 m showing for the first time the inter-locking of late Harappan culture with that of Painted Grey Ware.

Sub-period IA: It showed a late Harappan settlement on mud platforms. One such mud platform, measuring 4.25 x 10.0 m was found furnished with a landing step. After an accumulation of a deposit of 0.70 to 0.80 m (2.1 to 2.4 feet), the settlement was devastated by a flood.

Sub-period II: It is marked by the coming together of the late Harappan people. In the early stage of this occupation the settlement was faced by another flood. However the people continued to live at the site. Three phases of the structural activity have been noticed in this period. First, the people were living in round and semi-circular huts of wattle and daub. In the second phase, a 13-roomed mud-walled house with a corridor in between having two sets of rooms and a courtyard in the eastern side is available. In the final phase of structural activity, houses made of burnt bricks were built as indicated by a scatter of such bricks which came up due to polishing activity (Figure 2.8). Oval shaped structures are available which had a domical roof and perhaps appear to be connected with some religious practices.



Figure 2.8 : Bhagwanpura; Thirteen roomed house from the overlap period beginning of the second millennium B.C.

2.1.8 Hulas

Hulas, district Saharanpur (Uttar Pradesh), is located on the left bank of a dried-up tributary of river Yamuna. It revealed a five fold sequence starting from the late Harappan period sub-divisible into three structural phases having mud brick houses in lower phase and the circular huts in the upper levels.

The first Paleolithic sites in India were discovered in the Soan valley in Punjab. Accordingly this period is divided in three phases: Pre Soan, Middle Soan, and Later Soan.

Pre-Soan: characterized by flakes and hand axes of Abbevilliam, Clacto and Acheulian types.

Middle Soan: represented by chapping tools and bifacial hand axes similar to those found in Africa and Western Europe.

Late Soan: with implements notable for their more careful finish and the absence of hand axes. The Paleolithic seems to have been followed by a Mesolithic period, producing microliths of flint or semi precious stones, which are found in many parts of India.

2.1.9 Mohenjo-daro and Harappa

Then about 3500-300 B.C. metals make their first appearance. The site of Kot-diji (Sind), with its large citadel and its mud brick houses, is the first intimation of the Indus Valley Civilization which developed in the 3rd and 2nd millennia B.C. The two major cities of the civilization appear to have been Mohenjo-daro and Harappa. Both are distinguished by advanced urban planning. Most of the Mohenjo-daro was built of kiln-fired brick and the buildings were massed into "Super blocks" of 600 by 1200 feet. The major streets are 33 feet wide and run north-south intersecting subordinate ones, running east west, at right angles to the streets.

The most dramatic characteristic of the two cities and to a degree of other Harappan sites is a commanding citadel. At Mohenjo-daro it is a massive, mud-filled brick embankment which rises 43 feet above the lower city. On its summit are the remains of several impressive structures of which the most prominent is the so called Great Bath, Figure 2.9 and 2.10. The pool surrounded by a paved courtyard is 39 ft. long (north to south), 23 feet wide and 8 feet deep. It was entered at each end by steps and its bottom of sawed and fitted brick was sealed watertight by bitumen. On the citadel to the most of the Great Bath at Mohenjo-daro are the remains of twenty-seven brick foundations, which have been identified as remains of a sophisticated granary complex. The citadel at Harappa also displays a Great Bath and a granary but of slightly different design. The uniqueness of the citadel structures and their physical relationship to the lower city at Harappa and Mohenjo-daro hint at a social and religious structure with precedents for later Indian society.



Figure 2.9 : Summit at Mohenjo-daro.



Figure 2.10 : *The Great Bath at Mohenjo-daro pulp of various pulses (Urad, Mung etc.), molasses, even pulp from fruits (Bell for example).*

Assuredly the height of the citadel also had a practical purpose, in that it remained dry during seasonal floods. It is important to remember that Mohen-jo-daro shows nine levels of occupation towering over 30 feet above the present flood plain. These nine levels represent a period of more than seven hundred years. Recent boring have also disclosed that an additional 39 feet of occupational level exists below the present flood plain and these illuminate a continuing struggle with flooding which occurred into antiquity. A number of these lower levels predate the earliest level at Harappa.

Harappan pottery: Harappan pottery was in keeping with the logical and ordered mentality that conceived the efficient urban planning and drainage systems of the Indus cities. It consists of wheel turned items of wide variety which show the consistent characteristics and standards of an organized manufacturing system. Among the various shapes created, there are huge tall decorated storage jars, streamers, bowls with pedestal, pointed globets which stood in the ground and many other utilitarian forms (Figure 2.11).

It is expected that the kiln fired bricks were joined with the mortar mainly consisting of red lime mixed with white lime and Indus civilization had contacts with Mesopotamia. This is confirmed by the discovery of the seals similar to those of the Indus Valley at Tello, kish and to Elamite or Sumarian seals at Mohen-jo-daro. This civilization disappeared between 1800 and 1500 B.C. but was continued by a past Indus civilization.



Figure 2.11 : Harappan pottery.

2.1.10 Indraprastha in the Vicinity of Delhi

People are well aware of the name Indraprastha, but its geographical location is not very well understood. According to the legend, *Drona*, the diplomat of the *Kauravas* (the cousin of the *Pandavas*) in an attempt to appease the *Pandavas*, handed over half the territory which the *Kauravas* claimed to be entirely theirs, to them (the *Pandava's*). This was the kingdom of *Khandavaprastha* on the west bank of the river *Jamuna*, later the site of the *Purana Quila* (old fort, Figure 2.12). The *Pandavas* asked *Vishwakarma*, the divine craftsman, to build them a magnificent capital, which was named as *Indraprastha*. Its five palaces had gleaming crystal floors that were as clear as water. These were polished using curdled milk. When *Duryodhan*, the eldest of the *Kauravas*, came to visit his cousin's home he mistook a crystal floor for a pool of water and jumped into it. The Ruins of *Indraprastha* are shown photographically in the Figures 2.13 and Figure 2.14.

The excavation carried out by the Archaeological Survey of India in 1991 revealed Delhi's antiquity, the glorious site of *Indraprastha* of the great epic of *Mahabharata* [Verma, 1996]. Findings of the stone age tools earlier in the vicinity of *Anangpur* area had continuously indicated that prehistoric man lived in *Delhi* and its surrounding areas. More solid evident are the seven cities that are traditionally associated with the widespread area that is now *Delhi*. The information available through literary and archaeological sources, though small, yet confirms *Delhi's* antiquity and continuity.

It is significant that until the beginning of the present century, a village called Indrapat, obviously derived from Indraprastha, lay within the precincts of *Purana Qila* (Old Fort). In fact till late forties, the area within the boundaries of the fort presented a village like appearance and the surviving accommodation was used by the villagers as well as refugees after partition of the country in 1947. The villagers till then called it Pandava's Qila. The discovery of an Ashokan epigraph in Lajpat Nagar in South Delhi in 1966 seemed to have furthered the keen interest in the search of antiquity of Delhi and the location of the site of Indraprastha. Since the site near Anangpur has been confirmed as the site of prehistoric man, the reasons for its choice were attributed to the easy availability of water, raw material for food making and thick forest for game.



Figure 2.12 : The Old Fort (Purana Qila) in Delhi.(Photograph B.D. Shah; India Perspective, July 1996).



Figure 2.13 : Indraprastha ruins, while confirming the antiquity of Delhi, point to a much developed civilization [B.D. Shah, India Perspective, 1996].



Figure 2.14 : Indraprastha ruins, showing the integrity of the structure [Photograph, B.D. Shah, India Perspective, 1996].

But more than that, this region has inherent magnetism since time immemorial. It is this pull which seems to have drawn even *Pandava's*. After the division of their ancestral estate due to strife, *Pandava's* were offered the densely forested area of *Khandavaprastha*; they accepted even that. This area was also known as *Yoginpur*. Other places called *Baghat*, *Sonpat* (*Sonepat*), *Tilpat* and *Panipat* were the other “Pats” which were demanded by *Pandava's* from the *Kaurava's* (*Mahabharat*). Significantly all these places have yielded the grayware associated with the so called *Mahabharat* sites, which have emerged after the excavations at *Hastinapur* in 1950.

Before beginning the digging into the past era, the archaeologists tap the literary sources. To go deeper in this case, they looked extensively into Buddhist texts and *Jatakas* to find a definite direction. Epics and *Puranas* (ancient sacred scriptures) are the other sources taken into account. As mentioned in the Buddhist text, the present Delhi kingdom was known to have had many towns, villages and cities and *Indraprastha* was the most important of them all. Since these sources, as well as legends refer to events and conditions of much earlier times, these have been relied upon to a reasonable extent. Though the exact dating of the literary sources is not possible, their chronological sequence has generally been agreed upon. The Buddhist text has described the *Indraprastha* in much precise detail and glowing terms. This town, as described therein was well connected by roads to all the main cities of which *Benares* received a special mention.

An eminent archaeologist A. Cunningham asserted the probable date of occupation of *Indraprastha* as 1511 B.C. No direct evidence to support

the theory of the identity of Indraprastha with Delhi was found till late, though plenty of circumstantial evidence was there. The assumed location of Indraprastha was between the present Ferozshah Kotla and Humayun's Tomb along the banks of Yamuna (when it flowed in that area). But it had remained a vague guess till the excavations were carried out by the Archaeological Survey of India in 1955 and the site fixed to be in the lower mound in Purana Quila. Extensive excavations were carried out in 1966 and the following four years. Painted greywares, an offering stand in red and few other objects found there confirmed the theory and encouraged further probe.

According to the accounts in the Buddhist texts and other scriptures, Indraprastha included the present Meerut region in the north-east and parts of Kathiawar in the south east.

According to some scholars Indraprastha was founded by Meerut in the north, Gogdavantha in south. Mathura in the east and Dwarka in the west, *Suruchi Jataka* (a Buddhist text) also mentioned it to be a city of great fame.

2.2 The Beginning of the Historical Period

No traces of the art survived from the centuries between the Indus civilization and the Maurya period. The architecture must have been in perishable materials. It is only with the Maurya dynasty however in the 3rd century B.C. that the first stone structures appeared. Their high quality and imitation of wood-working techniques suggest that they were preceded by a long period during which wood was the only material used for construction. The first rock shrines date from the reign of king Ashoka. The technique probably originating in Achaemenid (Iran), which exerted a profound influence on India in this period. These are the sanctuaries hewn from the rocks of the Barbar Hills in Bihar. This imitate very closely to the structure of timber built temples covered with thatch. The brick foundation of Ashoka's palace at Patliputra shows resemblance with the palace of Darius in Persepolis. There are also free standing columns (lots) erected by the king Ashoka all over his empire, which with their bell shaped capitals and polished shafts are also reminiscent of the columns of Persepolis.

2.2.1 The Earliest Styles - Bhashut and Sanchi

The period of Sunga dynasty in the 2nd and 1st centuries B.C. emerged with the iconography of Buddhism known as Bhasut and Sanchi Styles. A specially Buddhist type of monument appears in free standing architecture.

the stupa, a brick or stone built structure designed to contain relics or for purely commemorative purposes. This massive building modeled originally on a burial mound consists of a hemispherical dome set on a low base and surmounted by a square balcony like member (harmonica) Figure 2.15. On top of this is a mast supporting one or more umbrellas. Round the whole structure is railing with one or more gateways with porticoes. The horizontal and vertical elements of the railings and the uprights and lintels of the gateways are fitted together with mortise and tenon joints as if they were made of wood.



Figure 2.15 :The Great Stupa at Sanchi [Archaeological Survey of India].

2.2.2 Sarnath Monuments

Sarnath where Lord Buddha preached his first sermon was once the center of light throughout the Buddhist world for 1500 years, but it is now only a story. It is situated 8 km. from the holy town, Varanasi (then called Benares) in the northern state of India Uttar Pradesh. It was called before United Provinces. In the third century B.C, the great Maurya emperor Ashok was the first to construct a number of monuments at Sarnath, which included the famous pillar with lion-capital, the stone railing, the Dharamrajika stupa and the Dhamekh stupa. After Ashok, several other monuments were built during 2nd century B.C to the 12th century A.D (Figure 2.16).



Figure 2.16 : The Monuments at Sarnath.

The Ashokan pillar surmounted by the magnificent lion capital which is adopted as India's state emblem bears the edict of Ashok and two other inscriptions of the Kushan and Gupta kings (Figure 2.17). The lion capital measures 2.3 m in height and has a bell shaped base with lotus leaves, around abacus with an elephant, a horse, a bull and a lion in relief and four seated lions emerging from one block of stone.

The Ashokan pillar was originally 15.25 m in height. The pillar has the base of 71.1 cm and it gradually tapers upwards measuring 55.9 cms at the top. In addition to the pillar, a beautiful railing of Ashokan time, 2.54 m long and 1.45 m high exists besides the main shrine. The Ashokan pillar as well as the railing have been made out of a single block of Vindhyan sandstone having a pleasant red shade. These are very well polished. The portion of the pillar embedded in the ground is also found on a large rectangular block of Vindhyan sandstone.



Figure 2.17 : The Ashokan pillar [ASI, 1998].

The *Dharamrajika* stupa which is 13.53 m in diameter was demolished by a local chief and now only a brick basement exists. The brick measures 49.5 x 36.8 x 6.4 cm. During the demolition, a relic-casket of green marble kept inside a large round stone-box was also found at a depth of 8.25 m from the top. This indicates that even in the 3rd century B.C marble was used for carving.

The *Dhamekh* stupa, another ancient monument with luxuriant stone work is considered by far the most important and sacred amongst the structures of Sarnath. Next to the *Sanchi* stupa of Bhopal, the Sarnath stupa is the only preserved large stupa of India. A shaft was dug vertically from the top of the Dhamekh stupa down to the foundation at a depth of 53.5 m. It was found that it was built of Mauryan bricks. This proved that the stupa was originally constructed by Ashok to commemorate the first sermon of Lord Buddha. It was reconstructed during the Gupta period (4th to 6th Century A.D) as is evident from the characteristic Gupta sculpture and script engraved in stone slabs.

It is a solid cylindrical tower 28.50 m in outer diameter at the base and 42.06 m in height. The basement is circular instead of the usual rectangular shape. The basalt 11.20 m portion of the tower is constructed of small layer of stone held together by means of iron clamps. Above this lies the cylindrical mass of the brick work. The outer facing up to half way from the base is girdled by exquisitely carved stones with ornamentation of geometric and floral designs in combination of birds and human Figures.

The beautiful pale red colored Vindhyan sandstone was used for the masonry layers and also for the carvings of the girdle of the stupa. The sandstone is fine grained homogeneous and durable and is superb for engraving and carving. The upper Vindhyan sandstone occur in abundance around Chunar 30-40 km. south of Sarnath. These might have been used for the construction. The thin bedded variety of sandstone was, however used by Gupta rulers for layered masonry works, and the huge blocks of the same rock obtained from the thick beds were used for the Ashokan pillars and railings.

2.2.3 Sanchi Stupa

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The Mauryan emperor Ashok also has selected the site and laid the foundation of the great religious center of Sanchi on a 51 meter high hillock southwest of Vidisha in Madhya Pradesh. There is a unique assemblage of nearly 50 monuments comprising stupas, monasteries, pillars, and temples. It remained the center of the religious constructions under the royal

patronage from 3rd century B.C to 11th century A.D encompassing almost the entire period of sublimation of Buddhism in India. Of the several monuments of Sanchi, the most spectacular one is the Great Sanchi Stupa (Sanchi stupa no.1) which is the biggest and best preserved stupa in India.

The Great Stupa of Sanchi is hemispherical dome with its top truncated and crowned by a triple umbrella (*Chattravali*) standing upright at the center of a masonry pedestal and surrounded by a square railing (Figure 2.15). The stupa is 36.5 m in diameter and 65.5 m in height. At the base there is a high circular terrace connected by a double staircase on the south meant for circum-ambulation. Another stone-paved procession path is present at the ground level. The railings measure 3.3 m in height and have posts of octagonal X-section at 60 cm intervals connected with three horizontal rails of 60 cm width.

The Sanchi Stupa has four principal gateways constructed in the first century B.C. The relief of the gateway or *toranas* are very beautiful. They constitutes of two square pillars 8.5 m height, each crowned by four lions, elephants or pot bellied dwarf's supporting a superstructure of three architraves. The gateway has carvings of horse and elephant riders, graceful figures and plant and floral motifs-the principal themes drawn from the lives of Buddha and *Jataks*.

The Great Sanchi Stupa with its massive railings and the four highly ornamented gateways and other stoneworks records one of the earliest use of Vindhyan sandstone for buildings, decorative works and carvings. Fragments of a stone umbrella of Vindhyan sandstone with mirror like polish have also been found. The original Stupa made by Ashok was half of its size. This was reconstructed by encasing it with dressed blocks of Vindhyan sandstone. The rock was either quarried locally or was brought from the neighboring hill of Nogauri. The casing of ashlar masonry with hammer dressed stones was affected by constructing an encircled envelop at a certain distance from the core, and then the intervening parts were filled with big slabs of stone. This is the most significant in the sense that it marks the beginning of the use of dry stone masonry in India.

The political bearing of Indian architecture is also illustrated by its expansion overseas. Hinduism, Buddhism and the general culture, specially from the south, spread to Burma, Indonesia, an Indo-China. These elements created not only a colonial form of Indian civilization in these regions but also found an architectural embodiment which was no less impressive than in India. Indian sculpture, too, was an accomplishment of this extension of art.

Indian political history made yet another destructive impact on her architecture. It is responsible for a completely one-sided view of ancient Indian architecture, in which the importance of the south is emphasized at the cost of the north. The impression, which exists is that south India is the land of temples and is different from the gangetic basin in material culture. This is due to the historical fact that the temples of the gangetic basin were destroyed by the Muslims, who razed to the ground all Hindu temples wherever they found them, except during the short period of Akbar 1556-1605. Even before the establishment of Muslim power in India, in the 10th century, sultan Muhammad of Ghazni had sacked most of the great religious centers in northern India in the course of his repeated invasions. As a result of this widespread destruction, Hindu and Buddhist monuments survived in northern India only in those regions into which Muslims did not penetrate - Bundel Khan, Orissa, Rajputjana, Nepal and Himalayan foothills. In the northern plain, temples began to rebuild only in the 18th century, when the Marathas became dominant.

All the surviving examples of ancient Indian architecture are religious monuments. No residential buildings or any other form of secular architecture have survived in the south, the elaborate palace complex of the Hindu Kingdom of Vijanagara was sacked by the Muslims after their conquest of the city in 1565. But Sanskrit literature contain numerous references to splendid mansions and palaces which rose to the sky and there can be no doubt that the domestic architecture of ancient India was elaborate.

2.2.4 Sravasti-An Ancient Buddhist City

Sravasti is not very well known *Buddhist* center like *Sarnath*. Nevertheless, it is one of the eighth places associated with major incidents in the life of *Lord Buddha*. *Sravasti*, capital of the ancient republic of *Kosala*, lies in between the district of *Balrampur* and *Bahreich* in Utter Pradesh. It was a rich trading center under the king *Prasenjit*, the ruler of *Kosala*.

According to legend, *Sudatta*, a wealthy merchant of *Sravasti* has met *Lord Buddha* at *Rajgriha*. He was very much impressed and became his disciple. He has invited the lord to visit *Sravasti*. But there was no monasteries (*Viharas*) and no suitable land. At last he found the place in the garden of prince *Jeta*, the son of the king of *Kosala*. The prince demanded a high price "as many pieces of gold coins as would cover the land". The wealthy merchant could cover all the land of the garden except a small part. The prince has built a temple .

A bas-relief sculpture of red sand stone, dating to the 2nd century B.C., found in *Bharhut*, illustrates this legend by depicting a bullock cart bringing the coins to the garden. *Sudatta*, referred to as *Ananthapindika* in *Pali* texts, is depicted carrying a water pot, a customary way of offering a gift. Facing him is a holy tree surrounded by some human figures, probably that of prince *Jeta* and his retinue. There are two buildings as well, bearing the names "*Gandhar Kuti*" (Figure 2.18), and *Kosamba kuti*. Lord Buddha acknowledged the pious gift by naming the *vihara* as "*Ananthapindika Asrama* or *Jetavana Vihara*" (Figure 2.19).



Figure 2.18 : The "*Gandhar Kuti*" at Jetavana, Sravasti [Khanna, India Perspective, 2001].



Figure 2.19 : The Bharhut has relief representing the life story of Jetavana [Aryan, Indian Perspective, Aug. 2001].

Sravasti became one of the favorite resorts of Lord Buddha. One landmark event was the conversion by Lord Buddha into a Buddhist monk of *Angulimal*, a robber who used to kill his victims, cutting off their fingers to add to the garland of the fingers he wore around his neck.

It was at Sravasti that, in the presence of many contemporary rivals and king *Prasenjit*, *Lord Buddha* is said to have caused a mango tree to burst forth in blossom and manifest as his own images in different *mudras* (poses). A sculpture on a stone slab from *Sarnath*, dating to the Gupta period (5th century A.D) depicts this legend by presenting fourteen figures of the Buddha in *five mudras*-*dharmachakra pravartana* (Moving of the wheel of Law), *dhyana* (meditation), *abhaya* (granting freedom from fear), *vara*(granting a boon), and *bhumi sparsha*(touching the ground)- in both standing and reclining -on- a-lotus positions. All the forms are shown to be emerging as the shoots from a common stem. With these incidents Sravasti became popular sites for the Buddhists.



Figure 2.20 : The votive stupas [Aryan, Indian Perspective, Aug. 2001].



Figure 2.21 : Anand Bodhi tree at Jetavana [Aryan, *Indian Perspective* Aug. 2001].



Figure 2.22 : The Sobhnath temple [Aryan, *Indian Perspective*, Aug. 2001].

After the age of Lord Buddha, Sravasti was forgotten till the times of the Mauryan emperor Ashoka, in the 3rd century B.C, when Buddhism was revived.

Ashoka erected two pillars on the left and right sides of the eastern gate of the Jetavana. One of these was topped by a wheel and the other by a bull, both of them are Buddhist symbols. Each pillar consists of an ornamented shaft, circular in section, and arising straight out of the ground, without any suggestion of a base, tapering like a trunk of a tall palm tree.

The inspiration of the shape is said to have come from the image of a man praying among a grove of trees, in the midst of nature. The technical skill and the decorative elements seen on the pillars are characteristics of the *Mauryan* period. These stone pillars are polished, imparting a lustrous finish, and has lasted more than 200 years.

The ancient site has been divided into *Saheth* and *Maheth*, the two distinct groups of remains. *Saheth* is the site of the famous Buddhist monastery known as *Jetavana*. The excavated remains consists mainly of plinths and foundations in brick, of the monastery and the stupas (Figure 2.20). These lie within an irregular enclosure. The most prominent landmark found at *Jetavana* is a *peepal* tree, known as *Anand Bodhi* (Figure 2.21). A sapling from *Bodh Gaya*, said to have been survived till today and is protected by steel mesh against the strong winds. This tree is the object of veneration among Buddhists from around the world.

Maheth the other site, is located about 500 meters north-east of *Sahet*, and has been identified as the site of the incident city of Sravasti. Subsequent excavations, such as those carried out by Dr. Vogel (1907-08) have exposed the mounds of *Kacchi Kuti*, *Pakki Kuti*, *Sobhanatha* temple (Figure 2.22) etc.

2.3 Transitional Schools

About 1st century A.D, a new and very artistic period begins. This is often known as artistic period itself. The art of this period shows the shadows of the Gupta Style of the 4th century.

The architecture preserves the same plans as before the Christian era, together with the forms of timber built architecture, though in more style. Gradually the amount of carved or painted decoration increases, particularly in the forms of depicting figures on facade and the columns. This acquires large bulbous bases and bell shaped capitals with human couples mounted on animals.

Free standing architecture is noted chiefly for its carvings. The period, with a higher base and a more globular dome. Other features found in this period are pillared pavilions and town gateways with barrel bolted roofs. As is seen in the Ajanta caves [Figures 2.23 and 2.24]. From this period too, date the earliest wall paintings known in caves at Ajanta, which will be discussed later.



Figure 2.23 : Ajanta caves in Deccan Basalts.



Figure 2.24 : Ajanta caves, Middle Hall.

At Amravati, District Guntur, Andhra Pradesh, in South Eastern India, the ancient *Dhamatyaka*, flourished as an important Buddhist center of art and culture in the third century AD. It remained in prominence till the thirteenth century. It is attested by a large number of inscriptions found at the site itself. The center of the main stup called *Maha-Chaitya* formed the principal focus of the Buddhist establishment and dates back most probably to the third century B.C. [Figure 2.25]. The majority of the inscriptions, however recording the gifts of carved casing slabs, pillars, uprights, cross bars, coping stones, etc., by hundreds of devotees, monks, nuns, lay worshippers from different parts of India belong to the second century AD.

when the *Maha-Chaitya*, including its railing underwent additions. The discovery of a good number of stone and bronze images of Buddha and stone figures of Buddha deities like Maitraya, Manjusri, Lokeshvara, Vajrapani, Hemka, etc. datable from the sixth to the eleventh century A.D. testifies not only to the prosperity of the Buddhist art and religion during the period, but also to the gradual transformation of Buddhism in its final *Tantrik Vajrayana* form. The Greco-Roman influence is seen in the Figure 2.25. The carvings are found not only on the railings and gateways but also on the body of the stupa. Their refined style is well suited to the stones employed, white marble or mamreal limestone. One of the masterpiece carving on white marble, which is known as Maya's dream is shown in the Figure 2.26.



Figure 2.25 : The great stupa at Amravati, represents a slab from its casting, c 150-200 A.D.; Marble height 6 feet 2 inches (1.88m).



Figure 2.26 : Carving on white marble, Maya's dream [ASI, 1998].

2.4 The Classical Style (Gupta, Past Gupta and Palasena)

After the accession of the Gupta dynasty the culture flowered. The plastic art practiced by the Indian professionals attained a high degree of perfection so much so that the period from 4th to the 6th century is known as the classical period of Indian art. Gupta art is characterized by extreme refinement and attaches great importance to the purity of form balance and harmony of proportions. In past Gupta dynasty Brahmanical art developed. The plan of temples showed the square cell, the abode of the God. It was surrounded by a corridor permitting the ritual circum-ambulation. The sanctuary was entered by way of a pillared portico, a hypostyle hall (*mandapa*) and a vestibule (*antarala*), all built over a basement level. The use of bricks have been increased.

The period is marked by the emergence of the monumental relief, but the Buddhist carvings lost their picturesque character and the facade of temples became covered with whole series of Buddha. The Brahmanical carvings developed on the other hand. The caves were constructed by cutting the rocks and the images of the gods were carved on the stones. They demonstrated the superhuman nature of the Gods.

2.4.1 Ajanta Caves

Ajanta caves, district Aurangabad, Maharashtra, is a renowned name in the world of architecture. Amidst a picturesque landscape of Deccan basalt, 101 km north of Aurangabad in Maharashtra, there occurs a small hamlet-Ajanta. It has 30 Buddhist rock cut caves which have won the admiration all over the world for their unique sculptures, carvings and mural paintings (Figures 2.23 and 2.24). The caves of Ajanta including unfinished one are thirty in numbers. Out of this five 89,10,19,26 and 29) *chaityagrihas* and the rest are *sanghaamas*. Discovered in 1919, they fall into two distinct phases with a break of nearly four century between them. The caves excavation started here in as early as 2nd century B.C and as many as six caves-two Chaitya halls and four monasteries were completed by the end of the 1st century B.C. The momentum of further excavation gained ground during the 5th-7th century A.D after an interval of nearly 400 years when 24 more caves were added and most of the famous sculptures were chiseled out and the masterpieces of the murals were painted.

The facades and the Chaitya halls of the Ajanta caves show intense ornamentation and carvings. Rocks were hewn out to make figures of classic qualities. The entire course of the evolution of Buddhist architecture can

be seen in Ajanta. The Hinayana type of images continued from 2nd century B.C to 2nd century A.D. During this time, images of Buddha on his different life stories and several human and animal figures were carved out on the rocks.

The Ajanta caves are excavated in a semicircular scarp of 75 m height overlooking meandering stream. Waghora that descends as a steep ravine with seven leaps. The caves have a horse-shoe pattern of arrangement covering a stretch of 550 m. Their floor levels are not uniform and they have got no symmetry in their subsurface distribution probably due to their excavation at different times. The individual caves were earlier isolated but are connected by steps.

The Ajanta caves have been cut into the 200 m-thick Deccan trap basalt. The thickness of individual flow varies from 1.5 m to 30 m. The various types of traps recognized in the caves are:

1. **Vesicular**
 - (a) hard vesicular with or without amygdalae porphyritic/non-porphyritic.
 - (b) soft vesicular with or without amygdalae porphyritic/non-porphyritic.
2. **Massive**
 - (a) Coarse trap-porphyritic/non-porphyritic.
 - (b) fine trap-porphyritic/non-porphyritic.

There is no significant variation in the mineralogical composition of the various flows occurring in the caves. There is no folding, faulting or tilting in the trap of the area. Ropy structures are present in several caves. In the excavation and carving, the soft vesicular variety is generally chosen for their ease in cutting. The vesicles in the basalt are usually filled with zeolite which falls off due to weathering giving the pitted appearance as seen in many of the sculptures. Two kinds of joints are present in the rock: (i) horizontal with spacing 2 m or more and (ii) steeply dipping towards NNW or ENE. Contraction cracks (up to 30.5 cm wide) formed due to cooling of basalt and later filled with material of subsequent eruption, are also present.

2.4.2 Ellora Caves

The Ellora rock cut caves, the most spectacular of India's monuments are located 29 km northwest of Aurangabad (Figure 2.27). The excavations were executed in different periods. The construction was started in 2.5 century A.D and was continued later in the 5th and 6th centuries A.D in the Buddhist style of architecture. There are hundreds of caves cut at Ellora. Out of these only 34 caves containing different sculptures are well preserved

and have been declared as protected monuments. The Buddhists were the first religious people to make 12 rock cut caves. These consisted of a prayer hall and attached monasteries. These were single storey excavations with one hall up to 35 m deep and 18 m wide entered through the verandah with long central hall containing different shrines or cells. Several others were 3 storey with a number of cells to accommodate at least 40 priests. The most notable of the excavated caves is the *Chaitya* hall which measures 26 x 14 x 10 m. In addition to the 12 Buddhist caves, there are 17 (Nos. 13-29) Hindu caves and 5 (Nos. 30-34) Jain caves).

In Ellora caves like in Ajanta caves Buddha in different forms is the main theme of the sculptural work. In addition human figures as attendants of Buddha, animals and birds have also been carved in stone. In Jain temples the images include *Ganesh* and *Tirthankars*. The Hindu temples contain sculptures of a number of gods and goddesses, specially those of Shiva in different postures. Furthermore, the images depicting themes of the Hindu epics like *Ramayana* have been carved out. In the *Kailasha* temple *Ravana* is shown shaking the hill on top of which Lord Shiva with *Parvati* is seated.

Ellora caves had been hewn in olivine-free basalt, which like Ajanta can be classified in the following groups:

1. **Vesicular**
 - (a) hard vesicular with or without amygdalae porphyritic/non-porphyritic.
 - (b) soft vesicular with or without amygdalae porphyritic/non-porphyritic.
2. **Massive**
 - (a) Coarse trap-porphyritic/non-porphyritic.
 - (b) fine trap- porphyritic/non-porphyritic.

The individual flow varies in thickness from 0.3 to 4.2 m. The main structural features include, (i) Primary S1-plane of lava flow, (ii) joint plane S2, and (iii) the ropy structure. The joints are either horizontal or are dipping at angles of more than 45°. The horizontal joint planes are generally filled with crypto-crystalline silica and zeolite. In the *Kailasha* temple of Ellora there are 23 horizontal joints in a stretch of 33 m. The massive traps are hard and dense and break with conchoidal fractures. The sculptures of Ellora have carefully avoided massive traps while choosing the site for hewing the caves.

The Ellora caves had been sculptured mainly in amygdaloidal traps which have innumerable vesicles measuring 4 to 5 mm. and are mostly filled with dirty white zeolite which impart a mottled appearance to the rock. The zeolite fall off due to weathering, resulting in a pitted appearance as is seen in many of the carvings. In addition to the vesicles there are 12

cavities of varying dimensions (average size 30 x 12 x 15 cm) in cave 17. These cavities are generally filled with secondary minerals like zeolite, quartz and chalcedony.

The amygdaloidal basalt flows have undulating tops and bottoms, and have limited lateral extent. The thin flows are invariably amygdaloidal and free from jointing. In case of thicker flows, lower portions are free from amygdalae and vesicles, and are jointed, while the upper portions have concentrations of amygdalae and vesicles and have no jointing. In majority of the flows pipe amygdalae are present at the bottom. Top surfaces of the flows are glassy and have become red due to alteration and at places have developed ropy structure.

The carvings are deteriorated due to close jointing, vesicularity, irregular flow boundaries, existence of pipe amygdalae, concentration of chlorophaete, presence of quartz veins etc. Flows cutting across the statues and the carvings are common. Thin grooves have developed along the flow junctions. The removal of Tatylytic material occurring along some basalt flow-boundaries have also affected the carvings in some caves such as in cave 3. The Hindu masons had excavated the western face of Ellora hill to make large halls of temples. Of these, *the Ravana-ki-khai*, *the Dasavatara*, *the Kailash*, *the Rameshwara*, and *the Dumar Lena* are the most prominent. Among these Ellora monuments, the entire Kailasha temple was scooped out of a hill of amygdaloidal basalt. The temple consist of four parts- the main shrine, an intermediate shrine, the gateway and the cloisters surrounding the courtyard. The temple stands on a 7.6 m high plinth. At the time of rock excavation, a deep three sided trench was made from the top of the hill to obtain massive blocks of rock of dimension 60 x 30 x 30 m. The different parts of the temples were then delineated and carved out. In the building of Kailash, thousands of skilled sculptors and rock cutters devoted their whole artistic talent blended with religious feelings; as they believe that the God see everywhere.

2.4.3 Elephanta Caves

Elephanta is a little island 11 km of Mumbai. Besides the picturesque surroundings, it is famous for the beautiful sculptures in a rock cut cave. This rock cut temple was built around 850 A.D. as the Ellora temple. It has the same style of architecture as that of Kailash temple of Ellora. It is a Shiva shrine. The beautifully carved columns of the hall and the entrance have square sections at the basal part that become circular with base relief ended with apsidal towards the top. The wall panels contain statues of different Hindu Gads and Goddesses. The large Trimurti of Lord Shiva in

embodiment of the Hindu Trinity depicting as God of creation, God of Protection and God of Destruction is most prominent amongst all the statues (Figure 2.28).

Like Ajanta and Ellora caves, Elephanta caves has been carved out in the Deccan trap basalt, and the carvings are mostly in soft vesicular type of flow layers. Removal of zeolite from the vesicles by the natural processes has produced pitted appearance to many of the carvings. Weathering along the flow junction and joint planes in the rock are responsible for damaging part of the temple.)



Figure 2.27 : Ellora caves, Kaillash temple, c 757-90 .



Figure 2.28 : Large Trimurti of Lord Shiva, Elephanta caves, early 7th century.

2.4.4 Kanheri Caves

There is a sprawling cave-complex erected about two thousand years ago about 10 kms. south-east of the *Borivalli* area in Mumbai. It is surrounded by a forest and is popularly known as *Kanheri Caves* (from *Kanhagiri*, corrupted form of *Krishnagiri*). This huge complex of *viharas*, and cave temples which is about 1500 feet above the sea level- is the largest amongst the Buddhist monuments of the pre and early Christian period (Figure 2.29). It has the largest Stupa in the front of the enormous *Chaitya* cave that was discovered by Dr. James Bird in 1839 (Figure 2.30). The scattered, straggling arrangement of the caves makes it extremely difficult to define its architectural character. These were excavated at different periods. Some belong to the pre-Christian era while others appear to have been erected in the second century A.D. Some of them came into being between 4th and 5th centuries A.D.



Figure 2.29 : Overhanging rocks shelter the stupas at Kanheri [Khanna, India Perspectives, Aug, 2001].



Figure 2.30 : Stupa for worship, interior wall display the Buddha and Bodhisatava figures [Khanna, Indian Perspectives, Aug 2001].

The architectural features such as octagonal pillars without a base and capital, is similar to those of the pillars found at *Ajanta* caves. In the interior of cave 3 is an inscription recording the name of the last ruler of *Satavahana* dynasty, viz. *Yajna Shri Satakarni* (Figure 2.31), C 172-201. A.D. However, a closer look surmises that the different components might have been constructed at different period. It seems that work begun at the pre- Christian period continued in the subsequent centuries.



Figure 2.31 : *Façade of cave-3 at Kanheri [Khanna, Indian Perspective, Aug. 2001].*

Two portions of this vast cave complex, comprising 146 caves, are the most significant: the *Chaitya* cave and the *Darbar* hall. These have been invested with the most impressively sculptured figures, some of which are as tall as 23 feet. The entrance to the *Chaitya* temple is flanked by the *Naga* deities, and as one looks to the left, a large stupa can be seen standing, ensconced in a large deep recessed niche. Both this stupa and the one in worship hall are reminiscent of the one that occupies the pivotal position in the *Karla* shrine. These are not hemi-spherical like the *Sanchi* stupa but cylindrical, a form that continued in use for several subsequent centuries by the protagonists of the *Himalyana* ideology.

At the entrance there is a large panel, featuring twin pairs, evidently the donors of this cave complex; two wealthy merchant brothers, *Gajasena* and *Gajamitra* (Figure 2.32).



Figure 2.32 : Donors couples in the great court [Khanna, Indian Perspective, Aug 2001].

The elaborate architectural components and significant sculpture in cave 3 are among the last of the monuments of the *Hinayana* phase in Western India. This is characterized by the vault-roofed *Chaitya* halls, this phase came to a close in the last quarter of the second century A.D.

In addition to the octagonal pillars without plinths and capitals, the other variety of colonnade columns at *Kanheri* have a pot base and inverted lotus capitals surmounted by pairs of lions, exactly similar to those seen at *Karla*, *Bhaja* and *Bedsa*. Yet another variety displays pillars that replicate the design of the *Elephanta* pillars, with cushion capitals, this indicates that this might have been erected around 500-550 A.D, in the same time zone as *Elephanta* caves. Even though the architect-sculptors worked here over the period of time extending from the pre-Christian eras through the early 2nd century B.C to the 5th century A.D. but the architecture and sculptures are not so much meritorious as that of the *Ajanta* caves, but they cannot be dismissed altogether.

The *Chaitya* hall, the temple, and the *Darbar* hall are the best caves in the entire complex. The caves 3, 4 and 66 are relieved with eminently impressive sculptures of the Buddha in varied sitting and standing postures. Alongside are the *Bodhisattvattas* with their female companions and other figures.

2.5 Wall Paintings

2.5.1 Rock Paintings at Bhimbetka

The rock painting is associated with the Neolithic cave people. The environment that has been so propitious for the growth and development of the Neolithic cave people can be witnessed at *Bhimbetka*, 46 kms away from the Bhopal, capital of Madhya Pradesh. These rock people familiarize themselves in "*Ghotkul*" (Figure 2.33) [Maiti, India Perspective, April 2000]. Here the cave paintings are found from Neolithic period estimated to be 2400 years before the present time.

The rock paintings fall into three distinct periods- those from 10,000 B.C, those from 5000 B.C, and those from 2,000 B.C. However there are controversies about the age of the paintings. There are more than 700 caves spread over a radius of 9 kms.

The life depicted in the cave paintings is one of tension, perhaps of fighting. In some, the warriors of the times are seen on the horseback with arms resembling spears and shields (Figure 2.34). These people seemed to belong to *pre-Dravidian* and *Aryan* ages.



Figure 2.33 : "*Ghotkul*"-where tribal people familiarize themselves [Maiti, India Perspective, April 2000].



Figure 2.34 : Warriors on horse back [Maiti, India Perspective, April 2000].

However, relating to the theme of the painting, it appears more plausible that they belonged to the following periods;

- (1) **Upper Paleolithic:** Paintings from this period are in the form of linear representations of huge figures of animals such as bison, tigers and rhinoceros.
- (2) **Mesolithic:** In addition to animals, human figures and hunting scenes are also seen. There are depictions of communal dances, birds, musical instruments, mother and child, pregnant women, men carrying dead animals, men drinking and burials taking place.
- (3) **Chalcolithic:** The drawings from this period indicate that the cave men came in contact with the plains people of *Malwa*, a neighboring area.
- (4) **Early Historic:** There is depiction of religious symbols, tunic like dresses and the existence of some sort of scripts from different periods- some religious beliefs are also presented, like *Trimurti* (three gods heads and one body) and chariots.
- (5) **Medieval:** The paintings from this period are schematic. In some caves, armed men and groups of animals are seen. There are also scenes of group hunting (Figure 2.35). It is a tribal culture to paint the walls of even a hut house with decorative figures and lasting colors (Figure 2.36).



Figure 2.35: Painting showing group hunting [Maiti, India Perspective April 2000].



Figure 2.36 : Tribal art displayed on the outer wall of a hut [Maiti, India Perspective, April 2000].

The instruments for the paintings are wooden branches of palm trees, which were crushed in the manner and form of present day paintbrushes. The colors used were made from vegetable extractions, soils and mixtures and pastes made with animal fats. These combinations have made the color durable. These are intact for thousands of years without fading.

2.5.2 Wall Paintings in Different parts of India

Walking through the villages of India one come across a diverse collection of wall paintings depicting gods, goddesses, ancestors as well as scenes from daily life, animals, birds, geometric patterns and even the planets of the universe. These could be painted on the thresholds, walls, hearths, doors, windows and other places. The colors used are drawn from nature, and their brush could be anything from their hands to blades of grass, bamboo or even twigs-anything with which they can draw. There are different types of paintings. Even the same style of paintings has been accomplished in different way in different part of India. Some of the painting styles are described here and are shown photographically in the Figures 2.37 to Figures 2.40 [Chug, 2001].

Pithora paintings drawn by tribals are significant for their size and the feeling of motion depicted in them. The lines are initially sketched on a white background with a knife, then outlines drawn and colored in. Found in *Chhota Udaipur* in Gujrat or *Alirajpur* in Bihar, *Pithora* paintings are as large as 12x6 feet. Most of these depict the lifestyle of the people, their rites and rituals such as birth ceremonies, the first hair cut (*Mundan*), the sacred thread investiture (*Janeu*) or even the marriage ceremony.

In the case of *Warli* paintings, while making the figures crosses are initially drawn before the other lines are added in. Dominated by geometrical patterns, a *Warli* painting depicts the importance of nature in the tribals everyday existence.

Madhubani paintings from Bihar are a colorful and meticulous work of art. Rich in color and imaginative in design, Madhubani paintings are drawn with a definite color pattern and harmony, depicting the life style, religious sentiments, people and even nature.



Figure 2.37 : Painting on the entrance of a hut [Chug, 2001].



Figure 2.38 : Painting on the wall [Chug, India Perspective, June 2001].



Figure 2.39 : Painting on a Haveli [Chug, India Perspective June, 2001].



Figure 2.40 : Painting of God Shiva on the wall [Chug, India Perspective , June 2001].

A real profusion of wall paintings, intricate and finely executed can be found in *Shekhavati* in *Rajasthan* in hundred of *havelis*, temples, cenotaphs, wells and forts. These are a wonderful fusion of art and life, in an open art gallery. One can see here a history of wealth and an ostentatious life.

Motifs depicting the influence of the *British Raj*, the changes that came about with it, are vividly painted on the huge walls used as canvas. The frescos of the *Shekhavati*, *Rajasthan*, are unmatched for their perfection.

Initially, the colors used were those available from natural resources and vegetable pigments, such as *kajal* (lamp black) for black, *safeda* (lime) for white, *neel* (indigo) for blue, *harakhata* (terracotta) for green, *geru* (red stone powder) for red, *hirmich* for brown, *kesar* (Saffron) for orange and *pevri* (yellow clay) for yellow ochre. Mixed in lime water and subsequently beaten into a plaster, they do not fade for a long time.

These are some of the creative expressions of the rural folks of India which have become a tradition and are recognized as such. There are still many more which are equally beautiful and remarkable. The people of *Banni* tract in *Kutch* district in *Gujrat* decorate their walls with relief's using clay, dung and mica mirrors. Similarly in *Madhya Pradesh* not only they create such reliefs but also create structure like balconies, partitions and niches in the same fashion.

This art form over the years has adapted both new materials as well as subject matter. Ever since the last decade of the nineteenth century, natural pigments have yielded to chemical pigments; paint and brush have also

become more common. In *Shekhavati* even the technique has changed and one can see more frescos being painted as they are longer lasting.

Even in the urban area, it is a normal tradition to draw different figures on the walls and floors in the house specially on religious occasions like *Deepawali*, *Holi*, etc. Mostly the sketches made are of god and goddess whom the Hindus worship. On the other occasions like *grah-pravesh* (inauguration of a house), marriage, the drawings are made on the entrance of the house, a sign of welcome, and good luck. These sketches are made with white paint made with lime or by making a solution of water and flour, or yellow color by mixing yellow ochra or *haldi*. Some times the drawings are made only by flour, specially on the floors. In the case of *kuccha* walls and floors, a thin plaster is done with dung and water, over which the drawings are made. In case of *Pukka* walls and floors, these are made directly. In south India, the sketches can be seen round the year, mostly on the entrance to the house. These are mostly done by women, who do not learn this art in the schools, but have learnt at home "hereditary". But this art and skill is fading out due to the lack of time mostly due to the economic reasons and the settings of new apartments, which do not give possibilities for making paintings or drawings. The people use to buy the readymade drawings and sketches from the market, appropriate for particular occasion and paste them on the wall, and worship.

2.5.3 Wall Paintings in Gupta Period

Wall paintings follow the same pattern as carvings and reaches its peak in the Gupta period with the frescoes in the Buddhist caves at Ajanta. Huge compositions were made covering the whole wall surface. The whole interest was centered on the human figures here and little attention was paid to the landscape. This is probably not the work of a single artist but a teamwork. The wall paintings of the post Gupta period have survived particularly at Ellora, Ajanta, Bagh, Sittandvasal, Sittabhinji, Trirunalapuram and Kanchipuram. The places in Bengal and Bihar followed the Gupta formulae without any addition of their own.)

This is displayed at the Elephanta caves (Figure 2.28). Mumbai. Here the temples are remarkable for their very fine carvings and for the famous Maheshmurti, a colossal bust of a three headed Shiva. At another cave, Ellora, the scenes illustrating the incarnation of the god Vishnu and the aspects of Shiva are of dynamic quality and are of notable significance. A few paintings at Ajanta, which have survived on the walls of the caves 9 and 10 belong to the Satavahana period. The paintings depict chiefly the scenes from the life of Buddha and the *Jatakas*, although there are paintings

of secular nature also. The paintings are executed on a ground of mud plaster in the tempera technique. Some of the paintings are shown in the Figures 2.41 and 2.42.



Figure 2.41 : Ajanta cave (17), Painting showing Celestial nymph.



Figure 2.42 : Ajanta cave, painting showing Apsaras.

Here the material and the method used for the preparation of the walls for painting in these caves will be discussed in detail.

The materials used varied from caves to caves. The reason of this variation is not very clear but it must depend upon the quality of the stones in the caves, which are not always the same. A few examples are cited.

Ajanta caves: The plaster to be applied on the walls for preparation for painting consisted of clay, cow dung, stone powder, rice husk and lime.

Sirgiria caves: The plaster to be applied on the walls of the caves consisted of tempered clay, kaolin rice husk, coconut fibers and lime.

Bagh caves: The plaster to be applied on the walls consisted of red clay, *Maurang*, lime and jute.

Mansoullas: The plaster to be applied on the walls consisted of powder of (*sankh*), *Katha*, pulses (*Mung*, *Urad*), molasses, boiled bananas.

The method of preparation of the wall is given in the book "Vishnu-dharmotar" written between 4th and 7th century. This preparation is done in 30 steps:

Step 1-3

Brick powder of three varieties (fine, middling and coarse) should be mixed with clay, one third of it in proportion. To this is added fragrant of gum resin, molasses, saff-flower (*kusum flower*) soaked in oil, all in equal proportion. To these two parts already composed is added powder of lime (three fourth burned) with *bel fruit pulp* and lamp black. The rest or the remaining fourth part is an addition of sand (a little more or less according to the experience of the skilful artist).

Step 4

Then it is soaked in water, stored in a pot so as to get bubricous and is kept so for a month.

Step 5

When after a month it becomes very soft paste it has to be very carefully taken out and a coat is applied by the skilled artist on the wall after testing that the wall is quite dry.

Step 6

The coating should be smooth, very fine, free from uneven patches neither too thick nor too thin.

Step 7-8

When the wall is dry after this coat and is still not quite smooth, it should be smoothened by an application of the clay bereft of *surjarasa* and oil by coats of lamp black. Further the surface should be frequently wetted with

Step 9

The wall dries very soon by so doing and does not perish after hundred years.

Step 10

In this way a variety of mosaic floors can be made in picturesque fashion by the use of two or different colors.

Step 11-13

When the wall is dry, on a good day, which is appropriate to the gana (deva in presence to marushya and rakshas), specially suited for starting the picture (*like punarvasn for Rama, Rohinh for Krishna, Mrigaria for Shiva etc...*), the painter dressed in immaculate white, pure in mind and body, having adored Vedic seers and uttered auspicious hymns (*swativakya*) and having bowed to the masters, facing to the east should start his work of painting.

Step 14-15

The wise artist should draw and fix up the proportions and positions of the figures. Then he should color the paintings with the colors appropriate in their different situations.

Step 16

The Primary colors are five: White, yellow, red, black and blue, with many intermediate tones.

Step 17

First the color scheme is arrived at by separating them according to the artists knowledge and capacity for creating the atmosphere in the picture as there should be produced hundreds and thousands of color tones.

Step 18

Blue and yellow mixed produce green. It may be pale with greater medium of white or deeper blue.

Step 19

According to the colors used quantitatively there is predominance of color, lighter darker or in equal proportions-making it three fold.

Step 20-21

With one tone predominant many tints are produced. Thus there is the yellowish green from *durva grass*, light wood pale green, green like green pulse and so on, which all can be produced.

Step 21-23

Blue mixed with white is a tertiary color, which again is manifold by predominance diminution's equal or less proportions of one or the other. Thus is formed the tint like that of the blue lily.

Step 23-24

Beautiful tints are produced by mixing in calculated proportions. Red *laksh* tin mixed with white like the *lodhra* flower becomes red like red lotus, color so charming. This again produces several other varying tints.

Step 25-26

The materials for colors are gold, silver, copper, mica, lapis. lazuli. red lead, yellow orpiment, red lac, vermilion, indigo and several more.

Step 27

Metal colors are to be laid delicately in thin sheets or by liquefying them by chemical methods.

Step 28

Mica becomes the solvent liquefier when added to iron. Thus when metal coloring is to be done, they have to be suitably prepared.

Step 29

The liquefier for mica is mercury. Hide glue and bacula resin glue act to fix and strengthen colors. Vermilion Juice is also used for this.

Step 30

The picture is painted with brushes of high quality hairs and with the colors strengthened by the glue of elephant hide, the juice of *durva* and bark resins cannot be destroyed even though washed with water. This has prolonged life.

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3. THE MEDIEVAL PERIOD

Numerous temples were built in various architecture types in the medieval period. In these constructions the influence of regional architecture could be clearly seen. However, the characteristics of earlier period were still found. The temples were of small size, and were let only by one door in front of the image. It was combined with the various elements, which had been brought together on the same basement storey in the past Gupta period—the vestibules, the pillared halls and the porch. All of them were embedded in a massive bulk of masonry. There was heavy ornamentation on the exterior of the temple, which attracts the attention. In this area a great variety of buildings and stupas were erected. Finally the temple premises was surrounded by a wall, forming a kind of religious township.

The sacred places known for Buddhism such as Bodh Gaya, Sarnath, and Nalanda still functioned and flourished. The Buddhist sites are shown in Figure 3.1. During this period a Buddhist convent at Nalanda (Figure 3.2) was established by the king Kumar Gupta in the 5th century, which became a leading university center in the 7th century. Nalanda University maintained its prestige under the Buddhist Pala dynasty (late 8th to late 11th century) and played a leading part in the development of *tantric* doctrine. In the year 1199 Nalanda was destructed by the Muslims which led to the end of Buddhism in India.

The treatises on architecture classify the temples in different ways, some according to their form, others on the basis of their distribution in particular areas.

The classification according to form may be based on the ground plan or on the type of roof. In the later case three main categories can be distinguished: The temple with a covered roof, the barrel vaulted roof, and the type with a pyramidal roof. All having in common "the false vault" formed of corbelled courses of stone laid horizontally, the form of roof structure almost exclusively adopted by Indians.



Figure 3.1 : Map of India showing Buddhist sites.



Figure 3.2 : Buddhist convent at Nalanda [ASI].

The temple with pyramidal roof, found in Pallava style of Mamallapuram (Figure 3.3) and the Chalukya style of Ellora (Figure 3.4) consists of a square tower decorated on the exterior with plasters and a stepped roof crowned by a monolithic block in the form of a dome. The various steps or tiers having an edifice of successively smaller size, set in regular formation above one another. One of finest achievements in this style is the largest temple at Tanjore built in the year cir. 1000.

The barrel vaulted roof-is a feature of very ancient origin. It is represented in the town gates of the Bharhut and Sanchi. But it was mainly used in the south from about the year 100. For the monumental gateways of large temples, the main structure belongs to the pyramidal roof type. These structures rectangular in plan, rise up in many tiers to the ridge stone which crowns the immense roof. At each end of the barrel vaulted roof there is a horse-shoe-shaped pediment and the roof ridge is ornamented with numerous decorative features.



Figure 3.3 : Temple with pyramidal roof, Pallava style, Mamallapuram, Shore temple, early 8th C.



Figure 3.4 : Temple with pyramidal roof, Chalukya style, Ellora, 757-90.

The sculptures have mainly architectural function, covering the wall of the temples. These sculptures are barely attached to the walls, which provides liveliness to the exterior of the temple. The artisans were also well acquainted with the metal work, specially with bronze. A bronze stupa was made at Nalanda as well as in south India, which characterized the craftsmanship of these workmen. A remarkable bronze created in Kashmir in the 9th century presents four faced image of Lord Vishnu. Some of the frescoes decorating the interior of the temple at Tanjore reflect some idea of the wall paintings of the Chola period (9th-12th century). These paintings show the same characteristics as the carvings, with a striking sense of rhythm, an attempt to achieve modeling by the use of color. But in the later period in spite of the charm, the quality of paintings and sculptures deteriorated. This decline in the quality is very clearly seen in the Vijaynagar period (14th-16th century).

Muslims invaded India in 13th century. During this invasion they have destroyed the monasteries and other religious centers. This has not only interrupted the development of Indian art, but have also led to the disappearance of the Buddhist art throughout India. During this period the sculptures both carvings and images are differentiated from earlier work by the flatter treatment of the figures, a simplification of the surfaces and a profound feeling for rhythm and decoration. Dravidian art developed in the direction of ornament and baroque decoration. The later temples are covered right up to the roof with an intricate crowded pattern of figures of divinities with many arms; of artistic quality. This can be seen in the Surya temple at Konarak (Figure 3.5).



Figure 3.5 : Surya temple at Konarak.

3.1 Temples made with Bricks

The temples were built using bricks or in stone masonry. Geographical position of these temples is shown in the Figure 3.6. The architecture of the temples with bricks and masonry is described separately.



Figure 3.6 : Map showing the temples build in bricks and in stone masonry.

3.1.1 Temples in the Indian State, Goa

Most people associate the Indian state of Goa with the advent of the Portuguese. Its antiquity, in fact, goes back to thousands of years before Christ. It is only in the recent past that the secrets of Goa's historicity have been unearthed [Ashoke Nath, 2001]. Goa's history can be traced back to the times of *Mahabharata* where it is mentioned as *Gomant* or *Gopakpattan*. The *Sutra-Samhita* refers to the area as *Govapuri*.

Recent excavations by the Archaeological Survey of India has shown the existence of some old temples both made of rock carvings as well as bricks. There existed ancient temple of the *Goddess Mahalsa* at *Verna* in the *Salcete Taluka*. The Portuguese destroyed the original temple at Verna in 1567, and the idol was shifted to its present site in Mhardol near Ponda. The tank of the *Goddess Mahalsa* can still be seen at the ancient site, preserved and maintained by the Archaeological department (Figure 3.7).



Figure 3.7 : Water tank at the old Mahalsa temple [Ashok Nath, India Perspective 2001].

The island of *Diwar*, just across Old Goa on the other side of river *Mandovi*, is an important Goan landmark. It contains the site of a tank which was part of an ancient temple dedicated to *Shri Saptakoteshwar*, the main deity of the *Kadamba* kings. The temple was destroyed by the Portuguese and what remains is just the tank (Figures 3.8 and 3.9). On the birthday of Lord Krishna, the idols of all goddesses were brought here for a holy bath. The tank was built in the bricks and was decorated by lime base masonry. It shows the skill of the ancient builders of the region.



Figure 3.8 : A tank excavated at Diwar [Ashok Nath, India Perspective, 2001].



Figure 3.9 : The decorated boundary of the tank [Ashok Nath, India Perspective, 2001].

The excavations by the Archaeological Survey of India at Chandor (ancient *Chandrapura*) situated 66 km. from Panaji, in the *salcete taluka* have unearthed the earliest brick temple in Goa. The excavations have confirmed that the town must have been in occupation from the *Satvahna* times (2nd-3rd century B.C), as the red pottery of this period has been found along the riverside.

3.1.2 Temples at Chattisgarh

Chattisgarh is one of the three nascent states recently carved out of the existing states of Madhya Pradesh, Uttar Pradesh and Bihar. Madhya Pradesh did not suffer from outside incursions and thus retains its architectural heritage undisturbed. *Bilaspur* and *Raipur*, the new capital, are two centers around which historical monuments are scattered over a radius of 40 to 70 km. The temples are built both of stones as well as with the bricks [Maiti 2000].

The Indol temple is a notable temple in Kharod (39 miles south-east of Bilaspur). It is built of bricks and has got some new features such as podium molding in *Kalsa* with triple leaves. The images of *Ganesha* and *Narasimha* appear on the south, of *Indra* and *Garuda-Narayana* appear in the east while *Kubera* is located in the north. The *Sikhara* or spire is curvilinear, heavy and was four storeyed. The door has three branches-the first carved with ornate diamonds with scrolls coming out of "makara" or crocodile heads, the third adorned by life-sized figures of *Ganga* and *Yammuna*. The lintel has *Siva-Parvati* in the middle, flanked by *Brahma*, *Vishnu* and coiled *nagas*. In form and shape and design, this temple is more advanced than *Sabaranarayana* temple and belongs to the period 650-675 A.D. This temple is being restored by the Archaeological Survey of India and constitutes a unique specimen in the temple style of *Mahakosala*, i.e. the Chattisgarh region.

The *Rajim-Rajivalochana* temple is situated near Raipur (Figure 3.10). Its ground plan is common to *Kuleswara Siva* temple and *Rama* temple at Rajim and to the *Lakshmana* (Figure 3.11) and *Gandheshwar* temple at Sirpur. They comprise of a Sanctum sanctorum, an *antarala* (recess) and *kapotapalli*. The speciality of these brick temples is that the Kalasa moldings are decorated with *Asoka* leaf design in a fruit shape. The *jangha* (middle) is dominated by plain Deccani style plasters. The Rajivalochana temple has a *triratha* sanctum, on top of which is located a pyramidal *sikhara*. This temple is said to have been inspired by the Vakataka style.



Figure 3.10 : A Nayika on a pillar at Rajivlochan temple [Maiti, India perspective, Dec 2000].



Figure 3.11 : A view of Lakshman temple at Sirpur [Maiti, India perspective, Dec 2000].

Kaleshwar Mahadeva temple is an engineering feat of that age as the temple complex is built amidst the confluence of the rivers *Mahanadi* and *Peri*. In fact, the technology to withstand the torrential flood waters of the monsoons was evidently known to the architects of this temple. The foundation pillars have images of *Mahisasurmardini* and *Kartikeya* mounted on a peacock.

Ram Chandra temple conforms to the *Panchayatana* style. The plinth is rectangular and the four stages of *Mahamandapa*, *Antaralaya*, *sanctum* and *circumambulatory* are retained. The pillars, which are richly decorated, constitutes the finest specimen of Indian heritage sculpture. Some of its unique images are of "*Salubhanjika*".

Sirpur, situated on the *Mahanadi* river in Raipur district, is a major town. Here, the brick-built *Lakshmana* temple is the best preserved. This temple was constructed during the regime of King Sadasiva Gupta-Balarjuna, by his mother, the Maukhari princes Vasata. It consists of a podium with *Khura-kumbha* moldings and ornamented *Kalasa* with *Asoka* leaves.

Sirpur also has two *Buddhist Viharas* which are brick-built and have an open courtyard encircled by pillared cloister leading to cells of monks. The entrance of *Mahamandapa* facing the main shrine chamber has a massive Buddha image flanked by *Boddhisattavas*. The main *Vihara* was constructed by Ananda Prabhu during the reign of King Sadasiva Gupta Balarjuna. This edifice resembles the architectural design of the *Lakshmana* temple.

Sirpur Ghandeshwar temple was a later construction. The temple was a later construction. The temple is brick-built with modern plaster and lime coatings. What is unique here is a statue of *Siva-Nataraja* and a *Salabhanjika*. The statue of *Siva-Nataraja* is dated to *Kala Kalachuri* period. The *Salabhanjika* may be dated early part of the first millennium. The main gate of the temple leading to the *sanctum* is very ornamented. There is an inscription, which relates that the temple belongs to *Padun* rule.

3.1.3 Nalanda University

The university of Nalanda, located 103 km southeast of Patna in the state of Bihar was once a Buddhist University of international fame. The construction of this great center of learning was started during the reign of Kumara Gupta (413-455 A.D), and the later constructions were taken up under the patronage of King Harshvardhan (606-647 A.D) and Pala kings (8th-12th century A.D). During the 7th century A.D. when Huen Tsang

studied here, there were nearly 10,000 students from different countries and the university was a six storey building. Nalanda passed into obscurity when Bhaktiyar Khilji destroyed this center of learning in 1197 A.D. (Figure 3.12).



Figure 3.12 : Nalanda University [ASI].

Excavation has so far unearthed 11 numbers of monasteries running north to south. Each monastery is of 62.5 x 51.5 m size and is surrounded by 2 to 2.3 m thick wall. There were large number of stucco figures of Buddhist deities on the sides of the entrance. Two rooms with vaulted roof, constructed on the principle of arch are still present. A row of temples was built facing these monasteries. Altogether 211 sculptured panels of granite were installed in the temples. A huge stupa was built at the southwest end. The rooms for the students with varandahs were constructed around an inner quadrangular courtyard (Figure 3.13). The pillars used in the construction were ornamented and carved with various types of figures. There was an observatory which was used for planetary studies.

The main temple was a gigantic structure of 36.6 x 36.6 m at the base, and its main shrine stood at 18 to 24 m above the ground. This imposing lofty structure was the result of six successive buildings. In the center, there was a small stupa built of half-baked bricks (46 x 33 x 11.5 cm) made of earth mixed with straw and rice. Recent excavations have brought out the remnants of a 24 meter high clay statue of Buddha and beautiful wall paintings of human and animal figures.



Figure 3.13 : Student rooms at Nalanda [ASI].

Superior quality and well baked bricks with mud mortars or lime concrete were used in the construction of the monasteries and temples of Nalanda. Wood was used in the construction of the roof. The floor and the pavements were laid on a bed of lime based concrete. The drains were made of brick layers with corbelled arch at the top. The bricks used in Nalanda do not show any effect of decay.

It was a common practice to make stucco images by mixing broken burnt brick pieces, with lime and later plaster them with a layer of lime. The clay for molding the images was prepared by treating ordinary clay with several natural indigenous chemical additives such as grains of barley, wheat, lac, pumpkin, milk, butter, cow-dung, oil etc. These were mixed with clay and water, kneaded for a fortnight and were left for a month to mature. These are discussed later in the chapter plaster and mortars.

Granite was used for the construction of verandah pillars, sculptured panels and images. In making big clay images like the 24 meter high Buddha, granite pillars were used as support for the legs. Basic rock was also used for making images.

3.1.4 Bodh Gaya Temple

Bodh Gaya temple is the holiest of the Buddhist temples, because at this spot, Gautama, the Buddha, after a long and arduous meditation under the *Bodhi tree* (*Ficus Religosa*) had attained the enlightenment (Figure 3.14). The *Bodhi tree* forms the nucleus of a great establishment comprising *Bajrasana*: the stone railing, the great Mahabodhi, Jewel walk, Vagisvari and Tara Devi temples and numerous stupas.

Emperor Ashok in 3rd century B.C., started the first construction in the area. It consisted of a polished sandstone slab (2.4 m x 1.41 m x 16.5 cm) carved with geometrical patterns and figures called *Vajrasana* or diamond throne. This carved sandstone slab rested on a one meter high ornamented brick platform within which there was a stiff clay ball consisting of gold and silver objects, pearls and gems. The plaster of the platform was made of pounded coral mixed with small fragments of sapphire, pearl, and ivory in lime mortar.

In the first century B.C., Kurangi, the wife of the King Kaushiki putra Indraghimitra constructed a railing surrounding a quadrangle area of the *Vajrasana* which is also made up of sandstone. The railing posts are 30-37 cm in thickness and 3 m in height. The railing was further extended by the Gupta Kings, using granite for the pillars, cross bars and coping. The sandstone posts contain carvings depicting Gautam's life, sacred *Bodhi tree*, the wheel, the stupa etc., while the carvings of pillars represent ornamental motifs and other characteristics of the Gupta period.

The Bodh Gaya temple is typical of the Mahayana architecture that developed in the Gangetic region during the first millennium A.D. (Figure 3.14).



Figure 3.14 : Temples of Bodh Gaya.

The temple was constructed sometime before the 7th century A.D. Heun Tsang, who stayed in India during 629-644 A.D. stated that this great temple was built by *Brahman votary of Shiva Maheshwara*. The Bodh Gaya consists of plinth on which rests a 54.8 m high square pyramidal tower of nine storeys. The main shrine chamber is 14.4 x 14.8 m externally and 6.2 x 3.9 m internally. A unique feature is the vaulted roof of the entrance porch and *sanctum sancutorum*. The front of the temple consists of a large niche in which a preaching Buddha image is enshrined.

The Bodh Gaya temple is built of bricks with clay mortar and coated with lime. The floor is paved with granite slabs and the double flight of steps built in the wall of the porch giving access to terrace and upper cell is also made of granite. The granites used for constructing the floor, steps etc., of the main temple and for the railings of Vajrasana are available plenty in the close-by areas. But the sandstone used for the Vajrasana and the early railings belongs to the Vindhyan Formation, available only at considerable distance. During its existence of 1400 years or so, the temple has undergone repairs and restoration several times.

3.1.5 Temples at Bansberia, West Bengal

The style of temple architecture that developed all over West Bengal during the period beginning from the late 15th century onwards marked a clear distinction from that of the early periods. A peculiar new style, better known as *Bengali style*, with three clear varieties, *Chala*, *ratna*, and *Chandani* or *Dalan* evolved during this period.

Chala or hut-style having curved cornices, imitating bamboo-huts of rural Bengal, became very popular. A variety of *Chalas* like *Do-Chala* (two roof surfaces), *Char Chala* (four surface roofs) etc. can also be found. *Ratnas* (i.e. pinnacled temple towers or towers placed above the elongated *Char Chala*) and *Chandani* or *Dalan* (i.e. one storeyed square or rectangular building) arrested the attention of Bengal architects for quite some time. Terra-cotta decorations and stone sculptures upon the surfaces of brick as well as stone temples, depicting *Puranic* and legendary scenes, made them more popular among visitors and devotees.

Temples throughout Bengal, more or less, belong to these three styles, except the *Rekha* variation, which is close to the Orissa temple style.

The *Hamsesvari* temple at *Bansberia*, however is in a class of its own (Figure 3.15). *Bansberia* is a small town in the *Hooghly* district of West Bengal. The temple is dedicated to the goddess *Hamsswari* has a magnificent structure displaying a peculiar architectural skill hitherto not seen in any of the temple styles of Bengal (Figure 3.16, Figure 3.17). This sturdy edifice does not strictly fall in any of the conventional styles. The shrine, however, has thirteen turrets and hence may be stylistically called "*trayodasa-ratna*) or thirteen pinnacled temple, which is a *Ratna* type. But the turrets are not characteristically of the conventional type. They resemble actual lotus buds and petals marked distinctly and from a distance, appear to be intertwined.

For the first time one may witness here a symbolic representation of human anatomy; the five vital nerves in the human body, namely, *Ida*, *Pingala*, *Susumana*, *Bajraksha* and *Chitrini*, are represented by the five staircases of the temple. A mediator intending to achieve spiritual emancipation is required to awaken these five nerves one by one by resorting to certain processes. The thirteen turrets resembling lotus buds are symbolic representations of the thirteen sages of the mind, which is shut to the light of knowledge and wisdom. These are twisted together in a string-like formation, symbolizing the knots that can be made to untangle and open up steps by step through meditation. The thirteen stages of the mind are like the lotus buds that can be made to bloom by practicing severe austerity. The supreme spirit or *Brahma* comes to reside in the highest stage when all knots of the said nerves are opened, and ultimate spiritual realization comes when one reaches the stage symbolizes by the topmost lotus bud which blooms once this stage is reached and the mediator achieves his goal.

The sanctum sanctorum or "*garbhagriha*" is the inner apartment of the edifice where the presiding deity, goddess *Hamsesvari*, is installed. It is preceded by an open hall where the devotees assemble. The sanctum and the audience hall are built of sandstone, though the turrets around it are made of brick. The ceiling of the audiences hall is decorated with frescoes depicting flowers and foliage motifs in a graceful style.



Figure 3.15 : The Hemseswari Temple [Ray, P. India Perspective, April 2001].



Figure 3.16 : Beautifully carved panels of the temple [Ray, India Perspective, April, 2001].



Figure 3.17 : *Terracotta figures carved on panels [Ray, India Perspective, April, 2001].*

The construction work of the temple was first taken up by King *Narsimha Deva* in A.D. 1799, but on account of his sudden death, it was withheld for some time before being resumed. The building was completed by his queen *Rani Sankari* in A.D 1814. An inscription indicating the date of foundation was placed above the main entrance to the temple. His grand father *Raghu Deva* was a pious king of the *Bansberia Raj*. *Rameswara Dutta*, the father of *Raghu Deva*, was the most prosperous ruler of the *Raj* and won from Emperor *Aurangzeb* the title of *Raja Mahasaya* in A.D. 1679.

Raja Narsimha Deva, who was an expert *tantric* and spent eight years in *Banares*, intended to erect a unique edifice to enshrine *Hamesesvari*. To fulfil his object he brought skilled architects from *Banares* to construct this building. But he could not live to see it completed. The work was consummated later at the hands of his worthy queen *Sankari* and remains till date a unique example of temple architect.

3.1.6 Gompa Temples in Ladakh

Hemis Gonpa is situated in the gorge of a narrow valley 43 km south of *Leh* upto *Karu* on *Leh- Manali* national highway and 7.2 km. From *karu* across the river *Indus*. It is hidden behind the spur of the *Zaskar* mountain range and is built on the slope of brown rugged just above *Hemis* village.

The *Gonpa* was founded by *Stag-tsang-ras-pa* under the royal patronage of king *Sengge Namgyal* (1590-1640). The construction started in 1602 A.D. and it was completed in 1642. Over the centuries, it had been expanded by additional structure with some modifications. The details of *Hemi Gompa* is given by Fonia of the Archaeological Survey of India, Lucknow circle in a case study [Fonia, 1999].

The *Gonpa* complex comprises *Dukhang*; *Tshong-khag* and *Dukhang-Nyingpa*; *Lhakhang Ningpa*, new temple dedicated to *Guru Padmasambhava* and number of smaller temples: Seats for his holiness *Dalai Lama* and his Holiness *Head Lama*, *Manager Hemis Gonpa*. *King of Ladakh*; residential complexes for *Lamas* and a dancing courtyard. The main *Padme* temple is four storeyed having a dancing courtyard. The courtyard had a colonnade (now dismantled) along two sides, under which musicians sit and above were general galleries. The walls of the galleries were decorated with wall paintings.

It is considered to be the largest and richest *Gonpa* in *ladakh* and is called *Gonpa* of the *Gonpas*. It is mainly because it owns the largest land estate of 810 hectares covering 51 villages. It has association with the royal family of *Ladakh* since its construction. *Lamayuru Gonpa* is shown photographically in the Figure 3.18



Figure 3.18 : Lamayuru Gonpa (in the clouds) [Rao, India Perspective, Sept. 2001].

The main building is four storied. The *Dukhang* is entered through a verandah which is resting on four wooden pillars. The verandah has been renovated and repainted and the walls are decorated with paintings. *Dukhang* is resting on 36 carved wooden pillars. The four central pillars rise upto the roof of the sky light. The walls are decorated with paintings.

The *Gonpa* building represents finest building technology and craftsmanship in *Ladakh*, where local material and skills have been used. The outer walls are white washed and battlement are ornamented with broad bands of red color and are surmounted with number of flags. The *Gonpa* complex is built on a hill slope, thus enabling the main temples to have a basement floor underneath to support the whole complex. The outward is considerably sloppy and the thickness diminishes rapidly with their increasing height. The main section of the wall is in dressed stone masonry in mud mortar with strong foundation.

The main temple i.e. *Dukhang* and *Tshong-khang* are rectangular in shape measuring 16 x 14.2 m. The beams of the roofs are supported on plain carved wooden pillars and covered with planks painted in various patterns on the outsides. The roof on the upper section is formed of beams of five to six inches laid one to one and a half feet apart. These are covered with small straight pieces of willow twigs about one inch diameter placed touching each other. The whole portion is covered with a thick layer of leaves and coat of well beaten clay. The floors are of earth but at some places are paved with small pebbles set in clay with flat surface upwards. The tip surface of the roofs and the open roof surface are then water tightened by local clay mixed with coarse sand. The clay from *Ladhak* called *markula* soil is very high in alumina and iron content, is very fine and cohesive sedimented clay. It works like a very strong binder. The mason also use local liquor, which works like chemical admixture and provides better durability and water tightness.

The roofs are flat and the edges are finished with low parapets. The parapets are formed by tightly fixed twigs with outward extending ends which are encased in timber and mud block frames. Just beneath the parapet wall is the band of timber with circular motif carved in it representing butt ends of joists.

The internal walls have been decorated with simple mud plaster, whereas the more important rooms have been finished with special clay plaster. The religious and noble rooms are embellished with fine and minute details of Buddhist iconography. The external decoration consists of mainly white wash with local clay. The double storeyed balconies surround the courtyard

from outer three sides. These balconies, six to eight feet in depth, have carved under columns/beams and colored pedestals with intricate carvings and paintings.

3.1.7 Nimya Khera Temple

Nimya Khera temple is a famous burned brick temple in Kanpur district (Figure 3.19). It is about 80 km. from Lucknow, the capital of the northern state of India Uttar Pradesh (see map of India, Figure 3.6). The temple is constructed on a slightly raised ground along with four numbers of subsidiary shrines of rectangular size. The *Shikhara* of the temple showing a *lata* of bold *Candrasalas* on the *Bhadra* and single *Candrasala* on the two angular facets of each *khand* capped by *bhumi-amlaka* on the *karnas*. The interior of the temple is plain but out side is decorated with carved brick work. The door-frame of the *garbhagritha* is made of stone showing *Gaja Lakshmi* on *latatabimba* while *pedyas* show bold images of the rivers Ganga and Jamuna.

It is important to note that the temple was originally dedicated to Lord Vishnu. But later on was converted into *saivite cult* as presently there is *Shiva Linga* in the center of the *garbhagritha*. The date of this particular temple is not absolutely known, but looking at style, it can not be placed later than 9th century A.D [Hassan, 1997].



Figure 3.19: Nimya Khera Temple, [ASI, Lucknow].

3.2 Temples made with Stone Masonry

3.2.1 Tirupati Temple, Vatican of the East

Tirupati—the abode of *Lord Sri Venkateswara* (the birthless one), also called *Sri Balaji* in the north, is a very popular pilgrimage center of India. It is respected as Vatican, Catholic centre in Rome, Italy, of the East. It is known for its sanctity, power and its much-fabled riches. It is located in the southernmost part of Andhra Pradesh. *Tirupati* usually represents both the temple-town at the foothills and the main pilgrimage center called *Tirumala* of *Sri Balaji* at 3000 feet uphill (about 1000 m).

The temple is one of the oldest in the country; its record history goes back to at least 2000 years. It is placed somewhere between 57 B.C and 78 A.D [Pentukar, 1998]. According legend, a local chieftain called Tondaman discovered the idol of *Sri Balaji* in a huge ant-hill on the hills, where he built a small temple and started daily worship. Over the centuries the original structure has grown enormously as one sees it today with the grateful additions made by puissant dynasties and various monarchs that include the *Cholas*, *Pandyas*, *Pallavas* and the *Vijayanaaras*.



Figure 3.20 : The golden vimana (tower) shines brilliantly against the lush green hills in the backdrop [Pentukar, *India Perspective*, September 1998].

The temple structure is an architectural wonder. It is small in size compared to the other famous temples of the south. Nevertheless, it is a marvel and attracts more people from all walks of life and from all parts of the country and abroad throughout the year. It is estimated that about 20 million people visit the shrine every year.

The image of the deity is profusely covered with jewels and precious stones from top to the toe. Even the *Vimana* (tower) above the sanctum sanctorum and the huge pillar in front of the deity are wrapped in sheets of gold that shines brilliantly against the lush green hills behind it (Figure 3.20).

From the artistic grandeur, the religious point of view and for its legendary riches, the temple of *Lord Sri Venkateshwara* is considered to be the second richest religious institution in the world after the Vatican City in Rome, Italy.

3.2.2 Mahabalipuram Temples

Most of the monuments of this ancient sea port 55 km south of Madras were built during the reign of *Narasimhavaram I and II* (630-728 A.D) of the Pallava dynasty (Figure 3.21). These are grouped as; (i) Monolithic temples constructed in the style of *rathas* or chariots, (ii) caves by excavating the hills for temples called *mandapa*, (iii) Masonry temples. (iv) sculptured scenes or carved hill edge. The five monolithic *rathas* are square or oblong in plan; pyramidal in elevation and varying in their oval dimensions. The *Dharamraj rath* constructed in Pallava style is the largest of all, having huge pillars in the portico with statues of lions, pyramidal tower and turret roof. The *Arjuna rath* is the most elegant of the group having beautiful *makartorana* on its three sides. The other three *rathas* named *Bhima*, *Ganesh* and *Nakula Sachdeva* have Buddhist type of architecture with an oblong base on which two or three story structures with small *gopuram* stand. Of the temples made of stone masonry, there is the shore temple characterized by the statues of rampant lions at intervals dividing the carved panels of the outer walls of the temple.



Figure 3.21 : Mahabalipuram temple.

Building temples and sculptures exclusively by hard rock like charnockite and granite was the first bold venture of the Pallava rulers. In a keen competition with their Chalukyan rivals who mainly used soft sandstone in construction, the Pallava kings were faced with the difficult task of cutting, quarrying and dressing these hard rocks. It was the motivated urge of these kings that “rock architecture” implied the creation of temples only at places where hills or rock exists. This brought a new concept in hard stone architecture in India. The Mahabalipuram monuments are built in Charnockite. In the masonry construction of the temples like shore temple also Charnockite has been used.

3.2.3 Minakshi Temple

The Minakshi temple (Figure 3.22) at Madurai in Tamil Nadu has been constructed by the rulers of the Nayak dynasty, who ruled Tamil country right up to Cape Comorin, after the fall of Vijayanagar kingdom in 1565. Shiva and Parvati were worshipped in Madurai since ancient times in the forms of Sundara Pandya.

The outer walls of the shrines and the other enclosed and Minakshi who were the divine ancestors of an old Pandya dynasty of this place. The Minakshi temple is actually a double temple dedicated to Shiva and his consort Minakshi.

Structure measures 259 x 221 m and each of the four sides have a large gateway, it is led through a pillared corridor with another gateway, also have *gopurams* of smaller size. The temple has a flat roofed corridor with three

aisles. The *sanctum* has a small tower rising above the flat roof. Courts and halls are located in the temples having colonnades of pillars. The figure sculptures attached to the shafts are very large, showing super workmanship.



Figure 3.22 : Minakshi temple.

The gigantic *gopuram* of the Minakshi temple were constructed by large blocks (up to 9 m high) of charnockite and thereafter of bricks. The huge monolithic pillars are also made of charnockite. The large blocks for which huge rock mass had to be quarried from distant hillocks, transported to the temple site and placed in proper position involved great technical skill and manpower.

3.2.4 Lepakshi Temple

The tradition of decorating the temple interiors with sculptures and murals was widely prevalent during the *Vijayanagar* period. Of all the temples of *Vijayanagar* period, the *Saivite* temple at *Lepakshi* is the richest in sculptural and architectural beauty. It is also well known for its exquisite paintings.

Lepakshi temple is situated in the Ananpur district of the Indian state of Andhara Pradesh. The earliest inscription in the temple complex dates back to 1538 AD: But even after five centuries, the temple retains its beautiful murals- in excellent shape. It is built in the *Vijayanagar* style, on a low rocky hillock supported by a hundred pillars, the temple is indeed a visual treat. Each pillar bears some of the finest sculptures found in South Indian temples.

The central hall-the *Natyamandapa* (dancing hall) is the finest part of the temple (Figure 3.23). It contains life size sculptures of musicians, dancers and *apsaras* (divine beauties).

One of the interesting aspects of the temple is the topless *Kalyanamandapam* (Marriage Hall), consisting of a number of pillars, each beautifully adorned with sculptures of celestial beings including those of the *Dikpalakas* (keepers of the directions) and *Rishis* (sages). However, it is not clear even to this day as to why such a beautiful structure was allowed to remain roofless.

Lepakshi temple is also famous for its unique, huge monolithic multi-headed *Nagaas* (Snake Phallus) (Figure 3.24).

Paintings found on a large scale on the ceiling are another remarkable feature of the *Lepakshi* temple (Figure 3.25). They narrate stories from ancient scriptures and also depict the social life of its times. Some paintings also depict the figures of two noble brothers, *Viranna and Virupanna*, who are said to have built this temple. Some of the paintings also show women in their contemporary apparel and sleek with round faces, fine eye brows, large expressive eyes and elaborate hair styles. The artist used bright yellows, blues, ochres and blacks of a technically high standard.



Figure 3.23 : *Natyamandapa (Dancing Hall) at the Lepakshi temple [Ramchander Pentuker, India Perspective, Aug, 2000].*



Figure 3.24 : A huge Naga (serpent) at the Shiva shrine [Ramchander Pentuker, India Perspective, Aug, 2000].



Figure 3.25 : The 15th century murals adorning the ceilings of the temple [Ramchander Pentuker, India Perspective, Aug, 2000].

At a short distance from the temple is the famous *Nandi* (the bull of Lord *Shiva*)- a monolithic sculpture said to be the largest in India

3.2.5 Mukhteshwar Temple

Bhubaneshwar once inhabited about 7000 shrines of which about 500 temples are in different stages of preservation. Out of these temples Mukhteshwar temples built in 975 A.D is the most elegant. It is 13.5 m long and 7.5 m wide and 10.5 m high. The structure is well proportioned and has a beautiful finish. In Mukhteshwar, the Orissan architecture achieved a harmony between the surface decoration and the profile of the temple. The walls of square halls have attained a special style with the windows flanked by projecting niches. Beautiful arches are present above the windows including those of the sanctuary walls. The temple is surrounded by walls and is approached through a corbelled arch supported on massive pillars. The carvings of the temple wall are delicate, distinct and intricately linked with each other. The arched gateway or *torana* is an artistic masterpiece. (Figure 3.26)

The builders of Orissa preferred the sandstone over laterite because it is good for carving, polishing and has good strength. The sandstone used in Mukhteshwar temple is dirty yellow, fine grained, even textured, hard and strong. The temple wall shows a pleasing brick-red tint which is due to the artificial coloring. No mortar was used in the construction of this temple but stability was ensured by the weight of the big blocks and by careful adjustment of their center of gravity. The stone blocks were so accurately dressed that only hair fine joints can be seen at block contacts. Iron clamps have also been used at places to keep the stones in proper positions.



Figure 3.26 : Mukhteshwar temple.

3.2.6 Konarak Sun Temple

The great temple of sun God at Konarak about 66 km. from Bhubaneswar in Orissa is built by King Narasimha Deva (1238-1264 A.D.) (Figure 3.27). The massive chariot shaped temple has twelve pairs of wheels symbolizing the twelve months, each pair representing the dark and bright halves of the lunar period attached to the seven horses representing seven rays of the sun. The vast scheme of work is based on the realization of the sun's vital radiating power. The carvings depict various activities like the circumambulation of pilgrims, operation of hunt, the jointing of the passionate *mithunas* in kisses, warm embraces or ultimate union. The beauty of this masterpiece of monolithic architecture has received admiration from all over the world. In the words of the noble laureate Tagore "the language of man is here defeated by the language of stone".



Figure 3.27 : Konarak sun temple.

—There are, however no proper explanation for the occurrence of the erotic sculptures on temples. No less doubtful are such modern pseudo-spiritual explanations as that the sculptures were intended to test the devotees, so that only those who remained unaffected psychologically by them were considered eligible to enter the sanctum sanctorum. Nor can the sculptures be regarded as illustrating the *Kama-Sutras* or *Tantric practices* and perversions.

Ancient builders made a perfect plan for the foundation-preparation and structural design. Their way of measurement is seen from the following [Bose 1945]:

"The height of the temple is to be decided. Then the thickness of the wall is to be fixed at $\frac{1}{18}$ th of the temple height. The outline of the temple should be $\frac{1}{3}$ th of the temple height. it should be dug in a slant from all the four sides. After every three *hastas* (1.35 m), it should have a level step. The foundation is built up in four layers of equal height. The lowest consists of coarse grained sand and the second of rough stone. These two layers are bound up with the earth into which they are sunk. The third layer is made of *markada* stones in the form of stairs in the lower part and in *bhadra* form following the outline of the temple in the upper part. Only the fourth layer is built with the stone and consolidated with mortar. It should be finished evenly with a cover of particularly strong and flawless stones, forming the head of the foundation. On this uppermost layer the base of the temple can be set".

The temple is made of khondalite having various shades like brown, yellow and of variegated color. In addition to the khondalite laterite has also been used in the construction of some of the small temples of the Konarak complex. The stones are damaged to different grades. It is due to the different mineralogical composition of the stones. Although most of the sculptures and carvings are built in khondalite, some important statues like that of the Sun God are of fine grained meta-basic rock which is greenish in color and contains actinolite, chlorite and some zoisite.

The huge figure (2 x 2 x 2 m) of the lion in khondalite weighing 25 tonnes meant for *Vimana*, might have been placed at a height of 52 m. The monolithic meta-basic rock mass of the nine planets when intact had the dimension of nearly 6 x 2 x 1.4 m and weighed 26.5 tonnes. The ease with which these rock blocks had been lifted and placed at considerable height is a marvelous feature of the skilled Orissan builders.

The stones used in the construction are not available locally but in the vicinity. It should have been a tuff job to transport the colossal quantity of heavy stones from a distance of many kilometers and to lift and set in position at a height of 52 m in an age not favored with the modern transport facilities. Obviously the stones were transported by rafts along distributaries in this part of the delta. The Chandrabhaga, now dried up, possibly served as the last artery of transport. The method of carrying stones at the working place is illustrated on a panel fixed on the temple of Siddha- Mahavira near *Puri*. Here the laborers are seen carrying poles, from which stones are suspended by means of ropes, along a wooden ramp supported on posts. The dependence was, thus, principally on human labor; yet, the possibility of the use of simple contrivances like pulleys, wooden wheels or rollers for lifting the heavy stones to heights cannot be ruled out.

Dressed stones used for structural work have mostly been placed without using mortar. These have been held together by iron clamps and dowels. Huge blocks of khondalite, at places supported on iron beams, have been used over the doors as lintels. The first floor of the main temple is supported on a big iron beam with smaller beams placed across. These beams are up to 10.7 m long with a cross-section of 25 X 25 cm. These beams though exposed to the salty air from the sea for seven centuries are, however free from rust. But the weathering effect on the khondalite is evident. It is due to the limonisation of the garnets and the feldspar has been altered to kaolinic and serpentinuous material and the garnet has been decomposed to a spongy mass of oxide.

3.2.7 Temples at Chattisgarh

Chattisgarh is a newly developed state of India with Bilaspur and Raipur the new capital. Around Bilaspur, there are Talegaon conglomeration, where two main temples; *Jethani* and *Devrani* are situated (Figure 3.28). Both these temples belong to the Gupta period. The *Jethani* temple located on the northern side of the complex, consists of a sanctum, an *Antralya*, narrow *makhmandapa*, preceded by a flight of steps, the lowest one being a moonstone. The plinth of the temple is molded and the foot i.e. *jangha* has large oblong niches and is crowned by *makara torana*. The main door is lavishly decorated with scrolls and floral and twisted garland designs. The door is decorated with the sculpted figures of *Kubera*, *Uma Maheshwara* in love parleys and also in dice-playing situation surrounded by *ganas*, *mithunas*, river goddesses with attendants, etc. The temple is divided in two parts where *Siva* along with attendants and *Gajalakshmi* flanked by *Vidyadhara* couples are seen. The lower side of the door frame contains the figures of fifteen *Siva* devotees seated in a *mandapa*.



Figure 3.28 : A view of the "Jethani temple" at Talegaon, Bilaspur [B.P. Maiti,



Figure 3.29 : Yamuna portrayed as “Dwarpala “ (doorman) at Pataleshwar temple door panel, [B.P. Maiti, India Perspective , Dec 2000].



Figure 3.30 : A door panel at the Sabrinarayan temple [Maiti, India perspective. Dec 2000].

The temple contains the unique images of twelve-headed *Bhairava* whose limbs, eyes, nose and chin are replicated by reptiles and organisms with bell-shapes. This image was discovered at the *Devrani* temple and resembles the *Vaktaka* style found at *Mandhal* in the Nagpur region of Madhya Pradesh.

The Talegaon temples are built in stone and are the only remnants of Gupta architecture and sculpture in the entire region of Chattisgarh. The Gupta style of molded/rounded figures with typical eye socket points and ornamentation on limbs can be seen. But the uniqueness of *Bhairava* statue indicates not only a departure from Gupta style in sculpture but also the predominance of *tantrik* cult in the *Siva* tradition.

The *Malhar* complex, located about 32 km from Bilaspur, was known as *Sarabhpura* during the rule of the *Sarabhpura* dynasty, as *Mahalla* during the *Panduvamsi* and *Somavamsi* rule and as a *Ratanpura* during the *Kalchuri* period. The place has been the center for the *Saiva* and *Sakata* cults. The stone temple found here is known as *Deol* temple, belonging to the 6th and 7th century A.D. There is also a brick temple devoted to Lord *Siva* of the same period. King *Sadasiva Gupta-Balrajuna* of *Somavamsi* dynasty was responsible for the construction of the temple- The other temple found here-the *Kedareswara* or *Pataleswara* temple- was a later addition.

At the *Pataleswara* temple (Figure 3.29), the sanctum sanctorum is located underground, accessible only by a flight of stairs. This edifice was built by the *Kalachuris* of *Ratanpur* to worship *Natyaavtara Siva*. The *Malhar* Museum has 16 dolls of the *Natraja* form of Lord *Siva*. The other *Siva* sculptures are the Lord dancing on *Padampitha*, with no hand in dance movement. Here the Lord does not represent any dance pose. Artistically, the execution and treatment of the stone is superb. There are more examples. The four armed *Siva* with his usual attributes, more dynamic dance posture, is clearly visible on the left side. Another proud possession of the *Malhar* museum is the eight-armed *Siva* carrying a bow and arrow along with the *triusla*, *katavanga*, *khappara* and *Sivalinga*. This is an example of perfect pose of "*Param Nartaka*". But most striking and only one of its kind in India is the sculpture of the ten-armed *Pasupati*.

The *Kharod Sabrainarayana* temple (Figure 3.30) in *Kharod* (39 miles south east of Bilaspur) has a large *varandika* but the spire of *sikahara* is less heavy and more curvilinear. The original doorframe contains a sculpted figure of *garuda* holding the tails of three *nagas* whose human busts trail down above the heads of the standing river goddesss on the doorjambs.

3.2.8 Jageshwar Temple

It is located at 38 km east of Almora town in the Kumaon Hills of Uttar Pradesh at a height of 1700 m. There was tremendous temple building activity at Jageshwar in the medieval period under the royal patronage of the early Katyuris (7th to 10th century A.D.) and late Katyuris (11th to 14th century A.D) who had erected about 200 shrines. Jageshwar temple is regarded as one of the most sacred *tirthas* in Kumaon (Figure 3.31). The oldest temple is the Mritunjaya temple constructed in the 7th century. During the 8th and 9th century other temples were constructed. Among them the Lakulisa and Natraj temples are each 10.5 m high. These have a plain and simple square plinth and broad horizontal moldings all along the roof. The frontal pediment is profusely carved with images of Lakulisa flanked with his disciples and the Natraj shiva in his dancing feat. Unique in the art, the sculptures bring out the religious urge of the age.



Figure 3.31 : Jageshwar temple.

3.2.9 Baijnath Temple

Baijnath, the home of holy trio-Shiva, Parvati and their son Ganesh is located 71 km from Kausani in the valley of river Gomti at a height of 1125 m (Figure 3.32). It had been a place of learning from the pre-Christian era to the 15th century. This part of the holy Himalaya had attracted several kings and their courtiers, artists and craftsmen resulting in a great deal of cultural

interaction and giving birth to the several monuments, sculptures and temples. Numerous temples have been built by the Katyuri Kings in 8th-9th and 12th-13th centuries.

Sculptures at Baijnath temples are among the finest to be seen in the hills in northern India. Locally available granite gneiss has been used in the construction of the temples and statues. These rocks have been excellently polished. However, partly weathered varieties have also been used in many cases, because of the ease in chiseling, for the carvings. The rocks used in the carving of animal statues like *Nandi* (bull) and the lion over the elephant are well foliated and partly weathered.



Figure 3.32 : Baijnath temple.

3.2.10 Masroor Temple

The famous *Masroor* temple is a fine example of rock-cut architecture. This temple complex in Himachal Pradesh lies nearly 22 km from *Kangra*. It lies to the north-east of the village, a rocky sandstone ridge, the main axis of which runs from north-west to the south-east. An outcrop of sandstone rock, the highest central portion of which has been separated from the rest by transverse and more or less parallel cuttings, it accentuates the crest of the hill. In the intervening portions of the rocks are sculpted a series of temples unique in the entire *Himalayan* region and comparable to the monolithic temples of *Mahabalipuram*, *Ellora* and *Dhamar* caves. Standing 800 meters (2500 feet) above the sea level, these temples command a magnificent view over a beautiful, well watered and fertile land.

The *Masroor* temple has an adjoining tank-large and rectangular-hewn from sandstone. It is nearly 50 m in length and is reputed to have water throughout the year. The remoteness and inaccessability of the temple has protected them from the muslim invaders, while their monolithic character has saved them from devastation during the major earthquake of 1905, which destroyed most buildings in *Kangra*.

The idols inside the temples are those of *Ram*, *Lakshman* and *Sita*. Perhaps Lord Shiva was originally worshipped here as indicated by the presence of the figures of *Shiva* on the top of the entrance. On the basis of its architectural and sculptural decoration the temple has been dated between 8th-9th centuries A.D. The monument is a complex of shrines said to contain more than 15 *shikhara* type temples; of these, only about 10 are extant. In the centre of the complex stands the principal and the most elaborately carved shrine- the *Thakurdwara*-enshrining black stone images of *Ram*, *Lakshman* and *Sita* facing east. This shrine faces a little to the north east while the two subsidiary shrines of decreasing size face a slightly outer angle. A similar arrangement of these secondary shrines appear to have formed the back of the monument so that the principal temple stood in the centre of eight smaller ones. The whole complex is hewn out of a more or less rectangular mass of rock.

The principal shrine consists of a square *garbhagriha* (*sanctum sanctorum*), an *antralaya* (*verandah*) and a rectangular *mandap* (*pavilion*). The magnificent doorway to the *garbhagriha* have five *shakhas* (vines) ornamented with graceful and dainty foliated patterns, bands of diamonds and figure sculptures. The tall pilasters of the *antaralaya* and the *mukhya-mandapa* are ornately embellished with diamonds, *ardhpadma* (halves of lotus flowers, a pair of *ghattapallava* (earthen pot and leaves) and other decorative motifs.

Above the cells of the main shrine, and almost level with now lost roof of the *mandapa*, the rock is cut as a flat roof, broken only by the main and other smaller *shikhara* (spires) which mark the sanctum of each of the eight smaller shrines. There is a marked difference between the heights of the main pinnacle and those of the surrounding shrines. From each side of the *mandapa* a staircase ascends to the roof terrace. From here the view of the mountains is glorious.

The complex is made of sandstone of varying fineness and strength. In some places the carvings are hard and well preserved and give an impression that they are a later production while in other places the sculptures are so weathered that only the faintest outlines are visible. But the actual doorway

of the shrine is in small recess. The ornamentation and technique of the pillars, door, and lintels is exceedingly beautiful.

It seems that there were four shrines at the fur corners of the complex. Only one of them is better preserved. Two pillars support the roof of the veranda. The *shikhara* of this possesses *Chaitya* style window carvings. Although such temples exist in various parts of the India, the monuments at Masroor stand out as one of the finest examples of rock cut architecture.



Figure 3.33 : View of Masroor temple complex [India Perspective, July 2001].



Figure 3.34 : Rock cut sculpture [India Perspective, July 2001].

3.2.11 Bhojeshwar Temple

It is situated in the town Bhopal, which is derived from the name “*Bhojpal*” or “*Bhojpur*”. A city by the name Bhojpur still exists about 28 km from Bhopal. It was founded by the legendary Parmar king of Dhar, Raja Bhoj (1010-1053 AD). Raja *Bhoj* engaged in an intense fight with the *Chalukyas of Kalyani*. Prior to this, he engaged in another fierce fight with the *Chandelas*, who defeated him. It is remarkable to see how Raja *Bhoj* saved his kingdom after a severe defeat at the hands of the *Kalacharis*. However, till the last days of his reign, he continued to fight and attack another dynasty of the *Chalukyas*, only to be defeated once again. Thereafter, he fell sick and died. His palaces were totally destroyed.

However, an unfinished Shiva temple “*Bhojeshwar Temple*” still remains (Figure 3.35). It stands on a simple square plinth 66 x 66 feet. It has no re-entrant angles usual in such buildings. The richly craved dome, though incomplete has a magnificent, soaring strength of line and is supported by four pillars. These like domes, have been conceived on a massive scale. Yet they retain a remarkable elegance because of their tapering form. It is divided in three sections, the lowest is an octagon with facets of 2.12 feet from which rises a 24 faced section. Richly craved above, the doorway is plain below, throwing into sharp relief the two exquisitely sculpted figures that stand on either side of the pillar.



Figure 3.35 : The Bhojeshwar temple at Bhojpur, [B.P. Maiti, *India Perspective*, April, 2000].

On the other three sides of the structure are balconies, each supported by massive brackets and four intricately carved pillars. The "lingum" in the *sanctum sanctorum* rises to an awe-inspiring height of 7.5 feet. it is set upon a massive platform, 21.5 feet square and composed of three superimposed limestone blocks. The architectural harmony of the *lingam* and the platform create a superb synthesis of solidity and lightness. This half finished temple has earned the reputation of "*Somnath of the East*". The temple is under restoration and reconstruction by the Archaeological Survey of India.

3.2.12 Khajuraho Temple

Khajuraho is situated in the Bundelkhand area, 44 km northwest of Panna in Madhya Pradesh. The temples of Khajuraho were mainly built between 9th and 11th centuries under the Chandela Kings (Figure 3.36). 85 temples were built between 950 and 1050 A.D., out of which only 20 are now in good state. The Khajuraho group of temples is the refined expression of the Indo-Aryan architect. These temples stand on a lofty platform terrace with a huge basement story with beautifully ornamented moldings. Over this stable base rests the *Jangha* or solid walls alternated with voids of the inner compartment- *sanctum sanctorum*, assembly hall and the entrance portico. The loftiness of the Khajuraho temples is enhanced by smaller replica turrets grouped around the main tower. The exterior decoration of the temple with parallel friezes is marvelous. The ceilings are supported by four heavily sculptured pillars.



Figure 3.36 : Khajuraho temple.

The temples at Khajuraho belongs to different sects but the sculptures are homogeneous. The sculptures include five types (1) cult images (2) family deities, (3) divine nymphs, (4) erotic themes, and (5) animals. The erotic sculptures are symbol of cosmic love, the philosophy behind it is that life's effort is to fight decay and death, and the challenge is symbolized in the mystic union of *Shiva* and *Shakti*.

The temples of Khajuraho are built on granite foundation after removing 0.5 to 1 m of overburden. The unevenness of the ground profile has been levelled by building raised platform-terraces of about 2.5 m height by using assorted granite blocks. Most of the temples at Khajuraho are constructed of fine granite. Vindhyan sandstone blocks of different colors brought from the eastern bank of the Ken river have been clamped at the exterior end. The top portion rests on columns and walls of the buildings.

3.2.13 Dwarka Temple

The famous Dwarka temple dedicated to Lord Krishna is located at western most tip of Gujrat overlooking the Arabian sea. The *Nij Mandir*, the inner *sanctum* of the original Dwarka temples dates back to 2500 years (Figure 3.37). The present temple constructed by the king Vajarah nabha is of the 10th century A.D. The Dwarka temple is five storied with a total height of 38 m. The building is supported on 60 columns and is crowned with a highly ornamented spire. The temple has pyramidal or spiral structures over the main *sanctum*. The arches are supported by pillars with ornate brackets. The wall panels and pillars are decorated with sculptures. Some of them are damaged due to the salt laden marine climate.



The temple is founded on coral reefs and is made of locally available monolithic limestone known as Porbandar-stone. Lime mortar has been used for binding the masonry blocks. The limestone is forminiferal and belongs to Porbandar formation (Pleistocene). It is hard and compact and is suitable for dressing, carving and polishing. Its density is 2.62 gm/cm^3 , absorption 17.7% and compressive strength 330 kg/cm^2 .

3.2.14 Aurangapur Dam

It is not only the temples which the artisans in the ancient period were well aquatinted to construct. They were equally good in the construction of dam. One such example is the Aurangapur dam (Figure 3.38). It is nearly 900 year old masonry dam across the Badearpur *nala* constructed by Raja Anagpal, predecessor of the last Hindu king of Delhi, Prithviraj Chauhan. It is located near the Arangapur village 20 km from Delhi towards Faridabad. The dam is weir type structure of 80 m length and 2.5 m width at the crest level. It has a longitudinal inspection gallery about 3 m below the crest which is fact an advanced technique in the dam design. The down stream face of the dam shows stepped structures.

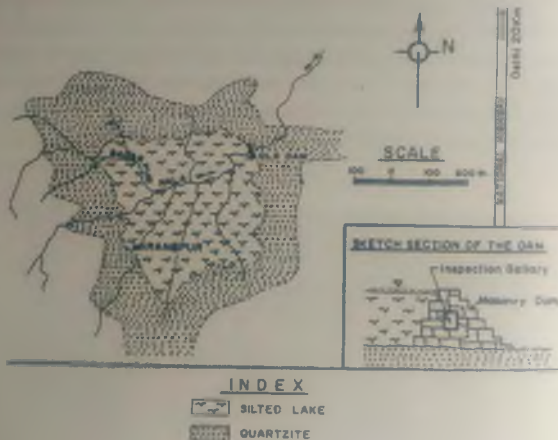


Figure 3.38 : Aurangapur Dam.

The reservoir has been silted up to a great extent necessitating raising its height three times during the last 900 years. The observed height of the structure at present is 6 m.

The dam is founded on well-jointed Alwar quartzite of the Delhi system (Pre-Cambrian), forming the Delhi ridge. For the construction material, rubble stone was obtained from the adjoining quartzite ridge. The stone blocks are set in lime mortar. The dam with its lake in the northern part of a bowl shaped valley is still operating, however, certain amount of water leakage is taking place through the foundation of the dam.

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4. INDO-ISLAMIC PERIOD

The architecture of India passed through different stages depending upon the ruling power at Delhi, which changed frequently in Indo-Islamic Period. To give an idea the history of Delhi with respect to the ruling power is briefed.

4.1 Dynasties in Delhi

The earliest reference to a settlement of Delhi is in the *Mahabharata*, where it is mentioned as the *Pandava* Capital of *Indraprastha* and is dated to the 15th century B.C (Section 2.1.10). The name “*Dilli*” appears in the records for the first time during the 1st and 2nd centuries A.D. But the city seems to have enjoyed little importance in the days of the great North Indian dynasties-the *Mauryas*, the *Guptas*, the *Tomara Rajputs* and the *Chahamanas*; 8th to 12th centuries A.D).

Delhi's rapid rise to eminence began with the growth of Muslim power after the city was captured by Muhammad Ghori in 1192. A list of different dynasties that ruled Delhi from the 13th century till India became independent in 1947 are given below:

1192 Conquest by Muhammad Ghori

1206 THE SLAVE DYNASTY

-Qutb-ud-din (1206-1211)

-Iltutmish (1211-1236)

-Sultana Razia (1236-1240)

-Nasiruddin (1240-1265)

-Balaban (1265-1287)

-Muizzuddin Kaiqubad (1287-1290)

1290 THE KHILJI DYNASTY

-Jalalddin (1290-1296)

- Alauddin (1296-1316)
- Mubarak Khan (1316-1320)
- 1320 -THE TUGHLAQ DYNASTY
 - Ghiyas-ud-din (1320-1325)
 - Muhammad bin (1325-1351)
 - Feroz Shah (1351-1388)
 - Mahmud Shah (1388-1396 & 1399-1413)
 - Nusrat Shah (1396-1398)
- 1398 -Sack of Delhi by Timur the Lame
- 1413 -THE LODI DYNASTY
 - Daulat khan (1413-1414)
- 1414 -THE SAYYID DYNASTY
 - Khizr Khan (1414-1421)
 - Mubarak Shah /1421-1434)
 - Muhammad Shah(1434-1445)
 - Allauddin Alam Shah (1445-1450)
- 1450 -THE LODIES AGAIN
 - Buhlol (1450-1489)
 - Sikander (1489-1517)
 - Ibrahim (1517-1426)
- 1526 THE MUGHAL DYNASTY BEGINS
 - Zahir-uddin Muhammad Babur (1526-1530)
 - Humayun (1530-1540)
- 1540 -THE SUR DYNASTY
 - Sher Shah (1540-1545)
 - Islam Shah or Salim Shah (1545-1553)
 - Muhammad Ali Shah (1553-1555)
- 1555 THE MUGHALS AGAIN
 - Humayun (1555-1556)
 - Akbar (1556-1605)
 - Jehangir (1605-1627)

- Shah Jehan (1628-1657)
- Aurangzeb or Alamgir (1658-1707)
- Azam Shah (March 1707-June 1707)
- Bahadur Shah (1707-1712)
- Jahandar Shah (1712-1713)
- Farrukshiyar (1713-1719)
- Muhammad Shah (1719-1748)
- Ahmad Shah (1748-1754)
- Muhammad Azizuddin or Alamgir II (1754-1759)
- Shah Jahan III (1759-1760)
- Shah Alam II (1760-1806)
- Akbar Shah II (1806-1837)
- Bahadur Shah II (1837-1857)
- 1798 -Delhi becomes a British Province
- 1858 -Bahadur Shah II departed to Rangoon, signalling end of the Mughal Dynasty, Also end of Company Rule in India and transfer of authority to the British Crown.
- 1911 -Third Delhi Durbar, Transfer of capital from Delhi to Calcutta
- 1947 -India attains independence. Delhi becomes capital of independent India.

4.2 Seven Cities of Delhi

Although it is not directly connected with the architecture, yet it is worthwhile to know about the historical background in the light of building construction. Seven cities were built around Delhi. These are shown in the map (Figure 4.1). The first of the medieval cities was built by *Anangpal* in the 11th century. A Rajput chieftain of the Tamara clan, he built a huge amphitheater at *Suraj Kund* and a citadel—*Lal Kot* on whose site the *Qutb Minar* now stands. Prithviraj Chauhan, the legendary Rajput warrior, during his reign (1179-92) built around this site; the ramparts of *Qila Tai Pithora*. *Lal Kot* and *Qila Rai Pithora* together constitute the first city of Delhi.



Figure 4.1 : Seven cities of Delhi.

THE MUGHAL KINGS*Babur**Humayun**Akbar**Jahangir**Shah Jahan**Aurangzeb**Figure 4.2 : Mughal kings who ruled India.*

Prithviraj was a courageous ruler. He fought many brave battles against the Turkish invader Mohammed Ghori. *Qila Rai Pithora* proving to be an impregnable fortress for a while. Ultimately Ghori was victorious and decided to stay at Delhi. The photographs of the Mughal kings who ruled India are shown in Figure 4.2.

After Ghori's death in 1206, his commander Qutb-ud-din Aibek enthroned himself. Qutb-ud-din had started out as Ghori's slave. But he was intelligent and faithful and so grew in Ghoris favour. By crowning himself the Sultan, Qutb-ud-din became the first of the slave dynasty. He began the construction of the Qutb Minar. Other illustrious rulers of this dynasty who followed included Iltutmish, Raziya Sultan and Balban. But the later Slave kings failed to emulate their predecessors and were overthrown in 1290 by Jalauddin- a Muslim ruler from a place called Khilji in Afghanistan. This was the starting of the Khilji dynasty.

The second of the Khilijis, Allauddin, was an ambitious man. He ruled with an iron hand and brought about many changes in the administrative system. He built Siri, the second of Delhi's cities, a little north of *Qila Rai Pithora*, in 1303 AD. The walls of this city were made of stone, brick and lime and it had seven gates. The Saljug empire of Central Asia was threatened by Mongolian invasions and people from it not only sought refuge in Allauddin's court but also made significant contribution to it. The central Asian influence is apparent in the horseshoe arches and the trellis work in the ruins at Siri. Allauddin also had a reservoir. Hauz Khas (Literally "special reservoir"), built for the residents of his new city. In 1320 AD, the Tughlaqs succeeded the Khiljis. The last of the Khilji rulers Nasir-ud-din Khusrau Shah, was actually a Hindu who had become a Muslim convert. He used his position as one of Mubarak Khan's favorite nobles to avoid that pleasure seeking Sultan and ascend the throne himself. But Khusrau's origin upset several sections of the people and he was eventually slain by the rebelling Turkish Malikis and Amirs led by Ghiyas-ud-din Tughlaq, the then Governor of Punjab.

Ghiyas-ud-din the founder of the Tughlaq dynasty, immediately ordered the construction of Tughlaqbad, the third city of Delhi, south east of the Qutb Minar. Work has begun in 1321. By 1328, Ghiyas-ud-din's new capital was ready. Nizamuddin Aulia, the revered Sufi saint at Delhi, had prophesised that Ghiyas-ud-din would not live to see his new capital. Strangely enough, when returning from an external campaign, Ghiyas-ud-din was killed outside the city walls in a palace coup plotted by the crown prince. All that survives of Tughlaqabad today are its curiously sloping walls in strong grey stone.

Muhammad Tughlaq (1325-51) built the fourth city of Delhi between *Qila Rai Pithora* and Tughlaqabad, naming it *Jahanpanah*, but the ruler did not stay long here. He transferred the capital to Daulatabad in the south so that he could administer the Deccan as well. The transfer was an absolute failure, resulting in terrible loss of life. More life was lost when the whimsical ruler moved his capital back to Delhi. All that is left of it today is almost entirely in ruins.

Feroz Shah Tughlaq (1351-58) was an astute ruler who undertook the repair and construction of many buildings. He also built a new capital Ferozabad, the fifth city of Delhi on the banks of the river Yamuna. What survives now is Feroz Shah Kotla with its magnificent Ashokan pillar. Some old hunting lodges have been discovered, one of which is exhibited in *Teen Murti House* (Prime Minister Residence).

The Tughlaqs were wiped out by Timur, the Tartar from Samarkhand. He came to Delhi in the first week of December 1398 and left after a fortnight, a bruised and bleeding city, scattered with the dead and the dying. The depopulated, poverty stricken city he left behind continued to remain under the Tughlaqs till 1413. Then from 1414 to 1450, the Sayyid Dynasty reigned in Delhi. It was founded by Khizr Khan, a Sayyid who assisted Timur in his Massacre. The Lodis who followed the Sayyids restored the prestige of Delhi. They ruled from 1451 to 1526 and during that period built many mosques and tombs, but for the most part, were involved in prolonged battles with the Mongol invaders. Finally they shifted their capital to Agra.

Babur, the Mongol prince, finally captured India after the battle of Panipat (1526) which became the beginning of the Mughal period in India. There eight Mughal Kings who ruled India. Their photographs are presented in Figure 4.2. His heart was not in the venture. He still yearned for his tiny but beloved Samarkhand. Legend says that when Humayun, Babur's son, was seriously ill, Babur walked round his ailing son's bed thrice saying "I have borne it away". Humayun recovered but Babur became sick and died soon after.

Humayun started building the Mughal capital of *Dinapanah* during the first phase of his reign (1530-1540), and continued its construction during the second phase (1555-56), but he was driven out to Iran by Sher Shah, the Afghan noble who had, by 1540, conquered most parts of northern India. He then built *Shergarh* on the site of *Dinapanah*. This was the sixth city of Delhi. It stretched from the *Lal Darwaza* at *Purana Qila* to the *Khumi Darwaza* at the outer edge of Feroz Shah Kotla. Sher Shah was a brisk, efficient ruler. The city of Shergarh flourished during his time.

Sher Shah succeeded by his son Islam Shah. He was a weak ruler and was soon overthrown by Humanyun. Humanyun lived for only a year after his return to power. His death was caused by a freakish accident. Descending his library steps, he took a fatal tumble. His widow Haji Begum built a memorial for him at Jorbagh- an impressive garden tomb, a precursor to the Taj Mahal.

Humanyun's son Akbar, then became the emperor. His unchallenged sovereignty over a vast empire, extending from the Himalayas to the river Narmada and from the Hindu Kush to the river Brahmaputra, his orderly administration, his policy of conciliation with the Hindus and his contribution to the finer arts and architecture, all mark him as the greatest Mughal emperor. Akbar, however, does not truly "belong" in the history of Delhi. Delhi was his capital for only eight years. He then shifted to his new capital Fatehpur Sikri, which he had built a few kilometers from Agra. Akbar abandoned the new city 14 years later as water was difficult to obtain. But he did not return to Delhi. Instead, he chose to make Agra the seat of his government and for the rest of his reign. Delhi was only a provincial city.

Jehangir, Akbar's son, who succeeded him to the throne, shuttled his head quarters between Agra and Lahore. Delhi, during his time, was ravaged by serious plague.

It was left to Jehangir's son, Shah Jahan, who came to throne in 1621 to restore to Delhi its imperial glory. This emperor, who made Agra immortal by building the Taj Mahal, found that city too small and so built his own capital in Delhi. This was named Shahjahanbad, and was the last of the seven medieval cities of Delhi. This populous city, still called old Delhi by many, includes some of the major attractions of today- the Red Fort, Jama Masjid and Chandni chowk. All the splendor and glory of Mughal rule was reflected in this seventh city of Delhi.

Aurangzeb ascended the throne towards the end of the 17th century, but his death in 1707 precipitated the total disintegration of the once mighty Mughal empire. What was left of it was plundered and reduced almost to a wilderness by the persian invader Nadir Shah who struck in 1739. Among his spoils were the Peacock throne and the *Kohinoor* diamond, invaluable treasures Shahjahan kept in the Red Fort.

The ruined city was a shadow of its former self. Even though it managed to recover from the shock of Nadir's invasion, its rulers were demoralized and a state of utter confusion reigned as *Abdali* and *Rohillas* from Afghanistan and the *Marathas* struggled to establish their supremacy over a Delhi where the Mughals still maintained a presence. This tug-of-war went on till the British decisively took over Delhi in 1803. Though then

capital was Calcutta, Delhi was not inactive. It was here when the first shots were fired during the great revolt of 1857, when rebel troops seated the trembling Bahadur Shah, the last of the Mughals, on the throne and proclaimed this aged descendent of Babur, their king. The euphoria was short lived, however, for the rebel forces were soon crushed by the British troops. The Mughal emperor was deported to Rangoon and his successors stripped of their titles.

However, in 1877, Delhi, with its imperial atmosphere so different from the then new commercial city of the British, Calcutta, was chosen as the site for the grand *darbar* of Queen Victoria. In 1903, at an even grander *darbar*, the accession of Edward VII was celebrated. In 1911, the third and the most spectacular of the Delhi *darbar* took place. George V formally announced at the *darbar* the transfer of the British Indian capital to Delhi. This was the end of Indo-Islamic history of Delhi.

This is the historical background of the building and development of the seven cities of Delhi. In January 1931, the city of New Delhi was inaugurated as the capital of the British Indian Empire. Today, the seat of the Government of independent India is located in what some call Delhi's eighth city.

4.3 Indo-Islamic Period Architecture

During the rule of the mohammedans, architecture in India passed through three different experiences. First of this was that the newly conquered forts were demolished and their material was ground to powder under the feet of fierce and giant elephants. This completely destructive phase was followed by a second one, in this the buildings were not ruthlessly shattered but were dismantled with the same aim. The ready-made material was supplied from this for the buildings construction of the conquerors. These spoils, however had to be supplemented in places by a certain amount of new and original masonry. Finally there was the third phase. During this period original well planned Islamic architecture came in view. Location of the prominent Islamic Architecture is shown in the Figure 4.3.

The architecture is thus divided into three main parts:

1. The Delhi or Imperial Style
2. The Provincial Style
3. The Mughal Style.

The architecture evolved during these dynasties was mainly associated with the rule at Delhi, which was the center of the imperial power. It began at the close of 12th century and continued for nearly four centuries. After that it was taken over by Mughals.

The second of these styles the Provincial Style, refers to those modes of buildings, made in other parts of the country in accordance with their own individual ideas.

The third style, the mughal was the latest and ripest form of Indo-Islamic architecture, which continued from the middle of 16th century until the 18th century.

4.4 Delhi or Imperial Style

Islam first came to India when Arab traders conquered Sind in 712. But the main thrust started later on when the Afghans, the Turks and the Persians came to stay. They established their capital at Delhi towards the end of 12th century. The architectural ideas of Islam were then introduced in India. Prior to this during two Muslim penetrations which are recorded, some buildings were constructed according to their needs. The first took place in 8th century, when the lower Indus territory came under the influence of the *Khalifs of Baghdad*. They introduced the glazed tiles decoration in this region. This can still be seen in Multan and its vicinity. The second penetration occurred when *Ghaznavids* entered Punjab from Lahore in the first half of the 12th century. In the old capital of Punjab ancient bricks and timber structures can be seen. This in the same way shows the style of the buildings prevailed in that period. Wooden doors and doorways may be found with ornamental riches, relating to the fashion of the many countries in West Asia during the first century of the past millennium.

The real beginning of Islamic architecture was in the last years of 13th century. Some examples of the architecture of his period are discussed below:

Qutub-Ud-Din Aibak, general and viceroy of Mohammed of Ghors Afghan Army, raised the earliest mosque in India on his victory over Hindus in 13th century. This has an open rectangular courtyard of 212 by 100 feet. This is contained on three sides by rows of stone columns brought from twenty-seven local Hindu and Jain temples. He has also constructed a tower known after his name, Qutub Minar. An Iron Pillar of the 5th century A.D., transported from a site near Mathura is also fixed in this area.



Figure 4.3 : Map of India; Locations of Prominent Indo Islamic Architecture.

4.4.1 Iron Pillar

The date for transportation of the Iron pillar is 5th century A.D but the actual time of its making could not be traced. However, the inscriptions on the pillar indicate that it was made during the reign of Chandragupta II (375-413 A.D) as a symbol of Lord Vishnu. The height of the pillar above the ground is 7.2 m (23 feet) and 93 cm of the pillar is embedded under the ground. It is one monolithic structure. This pillar is standing open to atmosphere even today without any rust or corrosion on it (Figure 4.4). Many metallurgists from different parts of the world have visited the site but the exact material from which this pillar was built, could not be ascertained. This indicates that the people in that time were very well versed with the technology of metals.

4.4.2 Qutub Minar

Qutub Minar (Figure 4.5) consists of four stories, diminishing as they ascend. Each stage is divided by a projecting balcony. In the plan the tower is circular, the base is 14.5m (46 feet) and 2.8m at the apex in diameter and it tapers to a pattern in section. It is 72.5m high with 379 steps. The lowest has wedge shaped flanges alternating with rounded flutes. The second storey has circular projection. The third storey is star shape while the fourth storey is simply round. On the northern side, it is entered by a doorway from where the stairs goes to each balcony, finishing with platform on the uppermost storey. In its artistic aspect the most elegant feature of this monument are the balconies and the design for their support. More original is the system of stellate bracketing underneath the balconies. By this their projections are supported and their weight is transmitted to the body of the structure.

The lower three storeys of the Qutub are made mainly of buff colored quartzite. But the upper two storeys are made mainly of marble with a subordinate amount of quartzite. Quartzite of the *Alwar Series* (Pre-Cambrian) is available locally. Whereas the marble was brought from different parts of Rajasthan. Sculptured Vindhyan sandstone, is reported to be brought after destroying the Hindu temples. From the inscriptions on the *Minar* it is evident that it was partially damaged in 1326 and 1368 by lightning and was repaired by the then muslim rulers.



Figure 4.4 : Iron Pillar.



Figure 4.5 : The Qutub Minar (1200).

The second great building monarch of the dynasty was Iltutmish (1211 to 1236 A.D). During the course of the development of the dome in India, it will be shown that various methods at different times were adopted. The particular method used in Iltutmish tomb was known as Squinch (Figure 4.6). Due to its construction, it became a notable landmark in the evolution of style. For in this building, three arches produced by means of radiating vousoirs, can be seen for the first time in India. In spite of the course nature of the masonry, which was a rubble foundation covered with cement, this tomb consists of a square domed chamber, 38 feet across have an archway on each of its sides, each archway is put together. In its narrow aspect it meant a definite advance in the structural practice but broadly it indicated something much more.

4.5 Delhi Khilji Dynasty (1290-1320)

After the death of Shams-ud-din Iltutmish of the slave dynasty in 1234, no important construction was done until the rise of Khiljis in 13th century. Advancement in the field of architecture specially took place when Ala-ud-din Khilji ascended the throne in 1296. This was the dynasty of Afganised Turks from the village of Khalji near Ghazni.

4.5.1 Alai Darwaza

One of the great structures of this period is *Alai darwaza* or Gateway of Ala-uddin (Figure 4.7). This appears fairly complete today. But minute inspection reveals that it has suffered a lot during last six centuries. The type of arches present here are known as the pointed horse shoe or "keel", a rare kind which are not normally used. The system of its construction is that of the radiating Vousoirs and is made of dressed stones. This was a distinct advance on the rough rubble arches of the previous regime.

In certain respects the interior of this building is even more informative than the exterior. Specially the manner in which the weight of the ceiling has been transferred from its circular rim to conform with the shape of the square hall below, is very artistic as well as practical. Above in each angle of the hall is an alcove, or semi vault of pointed arches similar in form to those of the exterior and by recessing one within the other, a support is formed, so that the circle is changed to the octagonal and the octagon to the square. This way the load of the dome is completely conveyed to the ground very gracefully. The arches pendatives however are only part of the arrangements of the interior hall. There are perforated stone windows at the sites corresponding to the arched recesses of the exterior. The walls are

covered by *Arabian* design, carved in low relief with other embellishments. This shows a new outlook particularly in the shape and inventiveness of the arches, in the method of its walling, in the system of support for the dome, in the conception of the dome itself and in the design of the surface decoration. A relatively small but interesting record of the association with the building art of Western Asia is seen in the structure productions at Delhi of this period. This is a method of stone masonry. The process consisted of laying the masonry in two different courses. A narrow course of headers alternating with a much wider course of stretchers, the former extending well into the rubble hearting, thus interlocking the whole into a firm bond. A similar system of construction is observable in the Parthian Palace of *Hatra* (El Hadra) in Iraq of 2nd century A.D, and in some of the buildings in Syria.

It can be understood from the above description that this entrance gateway (*Alai-Darwaza*) to the mosque of Ala-ud-din Khilji took a key position in the evolution of Islamic architecture.



Figure 4.6 : Tomb of Iltutmish (1235).



Figure 4.7 : Ailai Darwaza (1305).

4.6 Delhi / Tughlaq Dynasty (1320-1413 A.D)

Eleven rulers formed the Tughlaq dynasty. They have ruled for about hundred year only 3 out of the 11 rulers were interested in building art. Each of them has made and built his own capital city.

4.6.1 Ghiya-ud-din Tughlaq I (1320-25 A.D)

Ghiya-ud-din Tughlaq I was the founder of the dynasty. He has created a city known as Tughlaqabad near Delhi (Figure 4.8) This stands on the highest point of the rock. This is in two parts: i) a citadel corresponding to the castle and ii) the city. With this ruins it is difficult to believe that he built the great palace with golden bricks. They dazzle so much in the sunlight that it was rather impossible to gaze at them. The walls of the city were formed of earth or sun dried bricks. They were battered and this batter or slope was carried still farther eastward to be reproduced in the inclined stone walls and spreading towers of tughlaqs fortress-city at Delhi.

In contrast to the ruined condition of this rulers major work, his tomb is in surprisingly perfect condition. This tomb is built of red sandstone with certain portions including the dome of white marble. The most striking part of its composition is the slope of the outer walls. They are inclined at an angle of seventy five degrees, creating in a way the converging sides of a pyramid. The arches are pointed and each have its spearhead "fringe" But

in the case of tomb the horse shoe shape has been modified into one of more "Tudor" outline and there is a slight curve on the crown. The major difference lies in the conception of these archways in which for the first time the lintels across the base of the arch have been introduced. This provides two principal supports, the arch and the beam. A very artistic look was given to this by providing a bracket under the beam.

4.6.2 Muhammed Tughlaq (1325-51 A.D)

Muhammed Tughlaq was the son of Ghiyas Ud-din Tughlaq and successor of the thrown. His contribution to the capital of this area consisted in enclosing the space between the first and second cities by means of fortified, very thick walls. Very little of this great wall remains but certain buildings within have been preserved, for example a double storied bridge of seven spans (*Saat pul*) with supplementary archways and a tower at each end. The intention was to regulate the supply of water to an artificial lake which was one of the attractions of the new city. During his reign the capital was transferred to Daulatabad in Deccan.



Figure 4.8 : The city of Tughlaqabad (1325).

4.6.3 Feroz Shah Tughlaq (1351-88 A.D)

Feroz Shah Tughlaq was very much devoted to the building art. Due to the transfer of the capital from Delhi to Daulatabad, there prevailed the scarcity of the skilled labour. This has given birth to new ideas of building construction. Further more, the economic position was also such that he could satisfy his ambitions only by using other materials, which were inexpensive. Finely, coarsed and well finished sandstones ashlar were replaced with a method of walling in a completely different way. This consisted of random rubble work. The untrimmed surface was coated with substantial amount of cement. Essential structural features as lintels, doorposts, pillars etc were formed of roughly dressed monoliths. The decoration when applied was also not carved in stone but molded in plaster. Due to the masonry of this loosely knit order, additional strengths and stability was achieved by building certain portions thicker at the base than at the top.

To his credit are at least four fortress cities including the fifth city near Delhi known as Ferozabad. The devastating invasion of Taimur in the last years of 14th century brought to an end, the Tughlaq dynasty. For exactly 200 years Delhi had been the imperial center. The tomb of Feroz Shah Tughlaq is shown in the Figure 4.9.



Figure 4.9 : Tomb of Feroz Shah Tughlaq (1388).

4.7 The Sayyid (1414-51 A.D) and Lodi (1451-1526 A.D)

After the invasion of Taimur and the sack of Delhi, the imperial powers revived in Northern India. During the 15th century and also during the first quarter of 16th century, a number of buildings were erected in various parts of Delhi area, first under the rule of Sayyids and later the Lodis. But no great building undertakings are recorded in comparison to the previous time. No capital cities were founded, no imperial palaces, no fortresses or strong holds were created, no mosque of significance have been produced during this period.

Two different conventions were used for the tomb buildings. On the one hand there was a type designed on an octagonal plan surrounded by an arched colonnade or *veranda* with a projecting eave. This was one storey in height. Another type was square plan, having no *veranda* and the exterior being two and sometimes three storeys (Figure 4.10). In both the cases the building was surrounded by a dome. Frequently it is seen surrounded with a range of pillared kiosks rising above the parapet, one over each side of the octagonal type and one at each corner of the square variety. The three royal tombs of the octagonal type built during Sayyid and Lodi regime are those of; 1. Mubarak Sayyid, 2. Muhammad Sayyid, and 3. Sikander Lodi. Tomb of Mubarak Sayyid is shown in Figure 4.11



Figure 4.10 : Delhi; "Shish Gumbad", Square type (15th Century).



Figure 4.11 : Delhi; Tomb of Mubarak Shah Sayyid, Octagonal type (1434).

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5. PROVINCIAL STYLE

As already mentioned, there was marked regional influence upon the architecture. This has produced the buildings of remarkable beauty and of original quality, and were different than those having Islamic architecture. This type of regional architecture has been named as "Provincial Style". One of the important factor in establishing the provincial style was the character of the indigeneous arts which prevailed within the area of the province concerned, where this art flourished and the local artizans have produced the temples, mosques and tombs of very high quality in the past. The principal provincial styles are some eight in numbers. These are mentioned below :-

Punjab	1150-1325 A.D
Bengal	1203-1370-1573 A.D
Gujrat	1300-1572 A.D
Jaunpur	1376-1479 A.D
Malwa	1405-1569 A.D
Deccan	1347-1617 A.D
Bijapur	1490-1650 A.D
Khandesh	1425-1650 A.D
Kashmir	1410-

5.1 Provincial Style, The Punjab (1150-1325 A.D)

The first provincial style came in Punjab. The first contacts with Islam were made through the two major centers, Multan and Lahore. The pre-medieval architecture of Punjab was constructed mainly of bricks. One of the main reasons of using brick was the non availability of stones for building purposes. The brickwork done was of remarkably good quality. The bricks used were not unlike Roman builders, broad and thin. Additional strength was achieved by laying the bricks in upright course. This brickwork was reinforced by means of wooden beams, which were inserted in the walls. Thus the buildings were timber framed. These brick and timber walls provided greater stability (the battering surfaces being an ancient mud brick tradition). Wood was not only used in reinforcement but there were other substantial wooden elements also notably doorways, windows overhanging balconies etc. Combination of all this has given a very artistic wooden facade.

The effect of timber construction was overcome by decorating a part of the building by painted plaster and glazed tiles in brilliant color. Some of the remains of this architecture in Lahore and some in Multan show the design and mode of its treatment (Figure 5.1). There is nothing like this manipulation of wood in any other development of Islamic art.

Five tombs were built in Multan; 1. Shah Yusuf Gardizi (1152), 2. Shah Bahau-l-Haq (1262), 3. Shadna Shahid (1270), 4. Shah-Shams-ud-din Tikrizi (1276), and 5. Shah Rukn-i-Alam (1320-24). All these tombs were built in bricks with some wood work. The decoration was done with glazed tiles.



Figure 5.1 : Wooden doorway of a house (16th century) [Photo ASI].



Figure 5.2 : Multan; Tomb of Shah Yusuf Gardizi (cir. 1150) [Photo ASI].

The first four of the above mentioned tombs are square in plan. But the largest and most important is the fifth one. It is octagonal, with pronounced sloping outline in its lower storey. The octagonal base is 90 feet in diameter and its total height is 115 feet. Tiles were used to bring a bright color of its dull setting as well as to keep the sanctuary cool from the heat of Multan. The tomb of Shah Yusuf Gardizi is shown in Figure 5.24, 1993.

5.2 Provincial Style, Bengal (1300-1550 A.D)

The islamic architecture of Bengal is not a very impressive kind of building style. No doubt it rose to considerable heights as is seen in *Adina Mosque* (Figure 5.3) and *Dakhil Darwaza* (Figure 5.4). The principles of construction adopted were sound with their inventive and original appearance. More over they were very much suitable for the climatic conditions prevailed.

Mostly the building material used was bricks. But a great deal of the substructure of the facades was built of finely prepared basalt masonry. It is expected that for making basalt masonry the dismantled parts of the Hindu temples were used and it was not taken from the natural source of Rajmahal queries (Bihar). To suit the climatic conditions of Bengal i.e. excessive humidity and excess water during rainy season special constructions were made. The technique of construction is described below:



Figure 5.3 : Pandua, Bengal, Adina Mosque (1364) [Photo, ASI].



Figure 5.4 : Gaur, Bengal, Dakhil Darwaza (15th century) [Photo, ASI].

Most satisfactory results were obtained with the curved surface in this climatic condition. (Figure 5.5). The water does not accumulate in this case and thus there is no continuous absorption. Such curves in the structures were obtained by means of bent bamboo's, covered with thatch (dry-straw). The type of roof thus designed became a fixed convention in due course.

This style was not only confined to Bengal but has gone to further east for example to Assam. This can be seen at the entrance gateway at Dinapur in Sibsagar district. It has the central pointed archway. Octagonal turrets at each end and at the characteristic curved cornices.



Figure 5.5 : *Gaur, Bengal; Curved roof, At Kadam Rasul, Tomb of Fath Khan (cir. 1657) [Photo, ASI].*

5.3 Provincial Style, The Architecture of Jaunpur

Jaunpur, the seat of Sharaqi kingdom has acquired nomenclature for itself- the Jaunpur style. The Mughal emperor Shah Jehan admired this place as the “Shiraz of India” During the second invasion of Bengal in 1359, Feroz-Shah-Tuglaq camped here for six months and founded the city, calling it Jaunpur after the original name, Juna Khan, of his patron Mohammed-bin - Tuglaq. [Shahid Akhtar Makhfi, 20009.

Many fascinating monuments have been destroyed by the hostility of Sultan Sikander Lodi (1458-1477). What we see today in Jaunpur is a fraction of the monuments erected by the proud *Sharqi*’s. They have built bridge over the river Gomti, fort and mosques.

The bridge is very similar to the one built over the river Gomti at Lucknow. It was constructed with stones (Figure 5.6), and is known as the stone bridge. It took four years to complete it. The Mughal bridge with a long line of ten arches and piers was supplemented with further extension of five arches in order to cover the diverted channel, which *Alai* Ali-the architect from Kabul-was unable to cover. The bridge was originally provided with *Hammam* (public bath house) on the northern end. It has damaged and is closed. Atop the bridge there are numerous kiosks built in 1847 by the collector of Jaunpur.

The bridge in the words of General Cunningham :

“is one of the most picturesque in India.”

Its scenic beauty can best be left to imagination when the bridge often submerged during the monsoon and boats pass over it. It is remarkable to witness that inspite of the flood, during which the bridge is exposed to the aggressive environmental conditions, it is in very good shape. It speaks about its durability.

On the banks of the river Gomti is built Karara fort in 1360 by Sultan Feroz Shah Tughlaq with the materials brought in from the palace and temples of the *Rathuar* kings of Kannauj. With the advent of *Sharqis*, the fortification was further strengthened and numerous royal edifices added, which were destroyed and reduced to rubble by the Lodis a century later.



Figure 5.6 : Stone bridge over river Gomti, Jaunpur, [India Perspective 2000].



Figure 5.7 : Karar Fort, Jaunpur (cir 1360) [Photo, India Perspective 2000].



Figure 5.8 : Atala Masjid; Jaunpur (1408) [Photo India Perspective 2000].



Figure 5.9 : Jhanijiri Masjid, Jaunpur (cir 1430) [Photo India Perspective 2000].

The Mughal emperor Humayun and Akbar recreated the fort after extensive repairs. Much later, it was acquired by the Britishers and was damaged again during the first war of independence. The fort still offers a few interesting monuments together with eastern gateway that has been salvaged alongwith a portion of the fort wall (Figure 5.7). Within the fort complex, there is *Hammam of Sharqis*. Close to it is a three domed mosque built in a typical, Bangali style with a four feet high sandstone *minar* in front. There are arabic inscriptions on the *minar*, which assigns its construction to Ibrahim Barbak (brother of Sultan Feroz Shah) in 1377. It is a matter of controversy as some other historians read it as 1395 and credit it to Prince Ibrahim .

The earliest building to be erected by *Sharqis* was the *Atala Masjid* built in 1408 by Ibrahim Shah on the foundation prepared by Sultan Feroz Shah Tughlaq some three decades back (Figure 5.8). It is more ornate and beautiful compared to the Tughlaq monuments. However, the Jaunpur architects added their skill and ability in blending the tall screen with battered sides that created the dome on the eastern gateway of the prayer hall. The arched pylon theme is a unique feature of the *Sharqis* that veiled the dome from the front.

The style of the buildings that prevailed under the *Sharqi* dynasty of Jaunpur have been mostly confined to the mosques of Jaunpur. The main feature of the *Atala Masjid* is in the construction of rear wall. The plane of this retaining wall was relieved by three boldly projection surfaces, one corresponding to each of the principal compartments of the interior and thus coincides with the three domes above. Each corner of these projections is emphasised by a tapering turret, a larger replica being attached to the two main angles of the building itself. The whole arrangement has given a thorough solution of a difficult problem.

The next set of mosques were erected in 1430-Khalis *Mukhlis Masjid* and *Jhanijiri Masjid* (Figure 5.9). *Khalis* and *Mukhlis* were two nobles of Sultan Ibrahim, who ordered the erection of this mosque on the pattern of *Atala Masjid*.

Around 1450, *Lal Darwaza Masjid* was built together with a palace for *Bibi Raji*, (Figure 5.10). It is simplified reproduction of *Atala Masjid*, built on a smaller scale, to be used as a private mosque. Its entrance gateway is still painted red and hence its name, *Lal Darwaza*.

There is also *Masjid Jami- us- Sharqi*, the largest and the last mosque under the *Sharqis*. It was built in 1479 by Hussain Shah, the last of the *Sharqis* rulers (Figure 5.11). It is built on raised terrace. It follows the *Atala Masjid* pattern on a grander scale with fairly big halls without any

pillar or support of any kind. Its erection was ordered for the convenience of the holy saint, *Hazrat Khwaza Isa*, who used to suffer much during his walk to *Khalispur masjid*.

The largest and the most ambitious mosque of Jaunpur is the Jama Masjid. This is built on a terrace some 16 to 20 feet above its surroundings. The courtyard is a square of 21 feet side and the cloisters are two storeys in height. The three entrance halls, one in the middle of each side are of equal proportions, each with a beautiful dome. These lead to the great central pylon which rises high above everything at the western end of the quadrangle. On each side of this are arcaded wings of the side aisles. The roof of two large hall forming the transparent of the interior may be seen above these wings. The interior consists of the square hall. On each side of the central hall are the pillared side isles. These are placed transversely to the long axis of the sanctuary; each containing a second storey, the upper compartment with its openings filled in with perforated stone screens. This served as a private chapel for the ladies of the royal families. The designers have given a complete new turn in the treatment of the space beyond these isles. On each side is added a great vaulted hall corresponding to a transept (50 feet long, 40 feet wide and 45 feet high). Its interior was unobstructed by any support. Unique in these compartments of the transept is the shape and construction of their roofs, which take the form of a wide pointed vault. This in several aspects recall a Gothic college.



Figure 5.10 : Lal Darwaza Masjid, Jaunpur (cir 1450) [Photo, India Perspective 2000].



Figure 5.11 : Jami Masjid, Jaunpur (cir 1408) [Photo, India Perspective 2000].

The transept halls of the Jaunpur Jama Masjid are very interesting. There are no pillars or supports of any kind. Thus providing the interior with very clear open space. This is rare in the Indian architecture. Similar construction in the country is in the Adima Mosque at Pandua in Bengal. But its vaults which were of bricks have fallen. Where as in Jaunpur its roofs are intact and are in as good shape as when erected. To achieve their purpose, the builders first threw across the forty feet space a framework of four pointed arches consisting of two transverse ribs at wide intervals in the middle and two wall ribs at each end. This way permanent centering was achieved. The infilling formed of flat stones fitting on to the back of the ribs, were laid over it. Thus a solid stone shell, built of large blocks, materially homogenous resulted.

5.4 The Provincial Style, Gujarat (First and Second Period 1300-1458)

Most important provincial style was that of Gujarat. It is now the northern division of old Bombay presidency with its capital city of Ahmedabad. The Islamic style of architecture flourished in Gujarat for a period of two hundred and fifty years (1300-1550). The architectural style developed during this time may be divided in three parts. In the early period it was a customary to demolish. This was followed by reconversion. The second period started from the first half of the 15th century. In this period the art approached its early consumption. Finally there is the third period which occupies later half

of 15th century, even extended to the 16th century. The style in this period was in its most significant aspect. The credit goes to the ruler Mamud I "*Begarha*". Muslim rulers were dependent on the local labour for their architectural projects. These craftsmen were employed in building the Brahmanical and Jain temples from generations. In other words it can be said that the building art was their inheritance. This became very difficult for them to change from the traditional Hindu style directly to the Muslim structure. So the building style which flourished in Gujrat was strictly Islamic in every intentions, but a considerable portion of their compositions are adoptions from either Hindu or Jain temples.

In connection with these early Muslim buildings which are improvised from Hindu temples, it has been noticed that as a rule the pillars of the mosque are Hindu, while the walls are Muslim. This is true to certain extent as it was possible to use the pillars in the same form as originally executed with some readjustment. The walls were original as far as their construction is concerned, but the masonry was often composed of the stones from the temples but recut or otherwise reconditioned in order to fit in with the plan of the building to which they were being transferred. The best example of this phase is Jama Masjid of Cambay (Figure 5.12).

The second period of this provincial style started with Ahmad Shah I. He created the capital city of his reign Ahmedabad. Four mosques were amongst the chief buildings erected. Out of these four Masjid of Ahmedabad (Figure 5.13) is generally considered as the high water mark of the mosques designed in Western India, if not in the entire country. In theory, it is not far removed from the plan of constructing a temple building and introducing it into mosque sanctuary as a central compartment. To adjust this structure to its new position and purpose certain alterations have been made, such as the addition of second storey innovation of "rotunda" in the center.

In addition to the mosques described above, there is another significant building construction of this period "*Teen Darwaza*", a triumph archway (Figure 5.14). The chief attractions of this structure as a whole are the bold yet graceful shapes of its arches, the skilful arrangement of its parapet relieved by the three elegant oriole windows on the brackets and the form and rich carvings of the buttresses projecting from the front of each pier. But it owes much of its appearance to the contours of the arches which are very few in the Indian architectures as compared to those of buildings in Gujarat.

After the death of Ahmad Shah I, Qutub-ud-din reigned for seven years (1451-58). Several buildings were produced in this short time. Out of these one is his own mosque and the other is the mosque and tomb in the

memory of his queen. Besides this two more buildings were constructed, tomb of Darya Khan at Ahemdabad and the mosque of Alif Khan at Dhalka. These buildings are not built of stone like other monuments of Gujrat. They are composed entirely of bricks. Thus no beams or pillars are visible in their design. Their place has been taken by arches and solid brick piers. These were the two buildings of foreign style which found their way in Gujrat as judged from the character of the architecture and the structure process employed.



Figure 5.12 : Jama Masjid at Cambay (cir. 1325) [ASI].



Figure 5.13 : Jama Masjid, Ahemdabad (1423) [ASI].

5.5 Provincial Style, Gujarat, (Third or *Baghara* Period (1459 to approx. 1550)

During this reign of *Momud Begarha* at least three important cities were founded. Each on adorned with the noble buildings. Ahemdabad, the capital was made still more magnificent by his additions and improvements. The major of these buildings schemes were mausoleums consisting of the usual combination of a tomb and its accompanying mortuary chapel or mosque.

Masjid of Sidi Sayyid is of great importance. It is composed of arcades of arches, eight square piers support this to form the interior. Over this is laid a flat roof. In the construction of ceiling bracket, the diagonal beam and the squinch are employed. Walls of this mosque are composed largely of perforated stone screens of a character which has given this small and almost insignificant building a world-wide reputation (Figure 5.15). These screen did not only made the partitions but were also a means of providing light and air.

While the building art was maintained in the manner described above with its center at Ahemdabad, Sultan *Mahud Behara* created his new capital at *Champanirs*. It is situated seventy eight miles south-east of Ahemdabad. Most striking of all the buildings is the Jama-Masjid. This has a conception impressing upon the skillfulness of its parts and the symmetrical appearance of the whole. A noticeable feature of the exterior is in the rich treatment of its outer containing walls. This have received more artistic attention than most buildings of this type (Figure 5.16)

Besides the religious buildings described so far, some other structures were also taken up under Muslim rule in Gujarat. This has no less significance. Most utilitarian object treated artistically during this period was the sluice ways, regulating the supplies of water to the great artificial lake at *Sarkhej* palacial project and also to another water gate at *Kanhariya*.

Most artistic atmosphere of this period of Gujarat was illustrated by the architect of step wells or *wavs*, a common feature in the towns of western India. The *wavs or bauli* consists of two parts, a vertical shaft from which water is drawn up by ropes in the usual manner and an inclined passage way descending by means of flights of steps in regular stages to the level of water. Two of the most elaborate step well are the *Bai Havis Wav* in Ahemdabad (1499) and that at *Adaloj* (12 miles from the city built at the same time).

5.6 Provincial Style, Malwa, The Cities of *Dhar* and *Mandu* (15th century)

The provincial style of Indo-Islamic architecture in Malwa, a region towards the west center of the country, is the story of two cities *Dhar* and *Mandu*. No specific development of architecture or its allied handicrafts seems to have existed in this territory as the *Paramar* rulers were great patrons of literature. They have not given any noteworthy encouragement to the visual arts of their subjects. Due to this, trained workmen were obtained from the other cities and with them the characteristics of the Malwa style developed.



Figure 5.14 : Teen Darwaza, Ahmedabad (cir. 1428) [ASI].*



Figure 5.15 : Screen in the Masjid of Sidi Sayyidi, Ahmedabad (cir. 1515) [ASI].



Figure 5.16 : Jama Masjid, Champanir (1485) [ASI].



Figure 5.17 : Jama Masjid at Mandu (1440) [ASI].

Prominent innovation done by the hereditary artisans was an attractive method of combining the two architectural systems of the arch with the pillar and beam. These were formed from the temple materials. This has been done in a most artistic way. Another notable characteristics was to raise the buildings on the high plinth. So long an stately flights of steps were made as they were necessary to reach the entrance of the main building. These lofty terraces gave an added dignity to the composition as a whole and the well proportioned stairways provided an excellent introductory approach. Colour took a prominent part in the architecture scheme of *Dhar* and *Mandu*. This decorative property has made its structure one of the most striking. Due to the climate and other causes, much of this polychromatic ornamentation's has become considerably worn out or has completely disappeared. However remains are sufficient to prove that the workmen were color conscious. The color effect was obtained by two methods; partly by using colored stones and marble and partly by means of tiles. In the actual masonry of the buildings the principal material employed was sandstone of a lovely red shade. This was obtained from the nearby quarries of *Bijawar*. In addition to this the country around was rich in many kinds of marble and other stones of different tints and textures. The builders took full advantage of this material. In certain of the interiors semi precious stones such as Jasper, Agate and Cornelia were combined with the marble. These were used to obtain colors. But the most vivid borders and panels mainly in patterns of strong but harmonious blues and yellows painted on the tiles are distributed through out the buildings. This has emphasised in a most artistic manner their animated character. So much of this is even now traceable to confirm that there was a very flourishing industry in glazed earthenware at *Mandu* during 15th century and that the potters were devoted to their trade.

In *Dhar* and in some other examples of *Mandu*, the existing temples were dismantled and were converted to mosques. There are four prominent mosques two at *Dhar* and two at *Mandu* of this type. The largest and most impressive building of this great central group is *Jama Masjid* (Figure 5.14). The entrance hall to the mosque still bearing traces of some exquisitely colored borders and panels in glazed tiles. The manner in which this domed gate house rhythmically responds to the three similar domes of the sanctuary on the outer side of the courtyard is remarkable. Passing into the columned hall of the sanctuary one is struck at once by the effect produced by its repeating arcades of the arches. The manifold rows of which one within the other gives this interior a stately look.

In another phase of Malwa style the buildings in the form of summer houses, palaces and pavilions were built. The ground floor of which usually consisted of a series of compartments grouped around a central courtyard graced with pools and fountain, whereas above were arcaded loggias roofed with fluted dome, the surfaces everywhere decorated with painted tiles. These were *Baz-Bahadur* palace, *Rupmatis* pavilion, *Nil Kanth* palace and *Chisti Khan's* palace. The last example of the group at *Chanderi*, the *Badal Mahal* gateway (Figure 5.18), appears to have been a triumphal archway which is a tall structure of 50 feet height.

5.7 Provincial Style, The Deccan (1347-1687), Gulbarga (1347-1422), Bidar (1422-1512), Golconda (1512-1687)

The south of the Peninsula is known as the Deccan, corresponding to the present dominion of H.E.M. the Nizam of Hyderabad. Not like other Muslim rulers, rulers of Deccan have ignored the presence of the existing art of the country and have produced an original and independent style of their own.

The type of buildings that emerged consisted of the fusion of the architecture of Delhi (under Sultans) and that of Persia. The first period of architectural development of original character began in Ala-ud-din Bahmans period at Gulbarga beyond its outer shell. The one building which is preserved and protected, stands curiously isolated in the midst of a scene of devastating emptiness. This is the *Jama Masjid* (Figure 5.19). This is rare example in India of a mosque with no open courtyard. The whole structure is entirely covered by a roof. Thus it forms a class by itself.

The second period of the Deccani style of architecture was initiated by Ahamad Shah (1422-36). He has shifted his capital from Gulbarga to Bidar. The chief architecture of this period were the fortresses, palaces, two mosques within the fort, a school and the royal tombs. The style of architecture in nearly every instance was a variety of provincialised Persian. The chief characteristic of this style was the liberal application of color over the surfaces specially prepared for its reception. Due to this the brilliant mural paintings and color tiles are visible at the palaces. The later process of decoration is well illustrated by some of the tile work panels in the *Rang Mahal* at Bidar.

The third and the final place of the Deccani style is that came under *Qutub-Shahi* Dynasty (1512-1687). He has established Golconda as his capital. There are many examples of the architecture of this period distributed throughout the eastern part of the Deccan, but the most characteristics are those in and near the ruined and deserted city of Golconda.

All the Qutub Shahi tombs are of much the same type of design. This is based on that of the Bahmanis tomb at Bidar, but with the addition of many architectural and decorative elements chiefly of florid order. Besides the large number of mosques and tombs, the buildings which present the most real architecture value is neither a mosque nor a tomb, but a monumental structure erected in 1591 as a triumphal archway, now called *Char Minar* (Figure 5.20), at Hyderabad. It seems to have served the same purpose as Teen Darwaza built at much earlier date in the city of Ahmedabad, Gujarat (Figure 5.14). Char Minar is a composition of considerable size. Its square plan measured 100 feet side, four minars, one at each corner is 186 feet in height. Its ground storey consists of four spreading archways, one in each side of 36 feet span. Over this rise a series of diminishing storeys beginning with a substantial arcaded triforium and having a smaller arcade and a perforated balustrade above. Specially noteworthy are the minars, which in lightly leaping stages provide a soaring trend which is very essential in building of such a nature. At the same time throughout its entire composition there are evidences of the showy and attractive character which prevailed in the buildings of this period.



Figure 5.18 : Badal Mahal gateway, Chanderi, Gwalior state, 15th century [ASI].



Figure 5.19 : Jama-Masjid, Gulbarga (cir. 1367) [ASI].



Figure 5.20 : Char Minar, Hyderabad Deccan (cir 1591) [ASI].

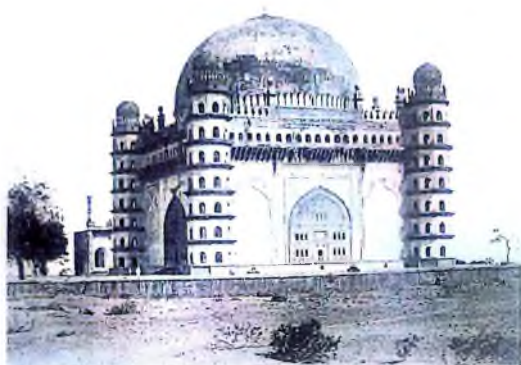


Figure 5.21 : *Gol-Gumbaz, Bijapur, Tomb of Mohammed Ali Shah (cir. 1660; [ASI].*

5.8 Provincial Style, Bijapur (16th and 17th century)

Bijapur was a medieval kingdom in the south of India. This has gone out of the hands of Bahmanis in 1420 and flourished till 1686 when it went into the hands of Mughals. Three types of buildings were made during this period—mosques, tombs and palaces. The building art of this new deserted capital can be illustrated by four remarkable examples. These are Jama Masjid; one of the earliest monuments to be constructed and so very simple, “the *Ibrahim Rouza*”, one of the most elaborate, “*Gol Gumbaz*”; showing the style in its most grandiose form and “the *Mihtar Mahal*” depicting its most refined and delicate manner. Amongst these *Gol Gumbaz* is of great importance.

Gol Gumbaz is the mausoleum of Mohammed Ali Shah (1627-57). He has produced his memorial as one of the largest and most remarkable single buildings in India (Figure 5.21). The tomb building itself is only one item in an architectural scheme of considerable magnitude. This comprises a mosque, a *Naqqarkhana* (drum house) and other structural amenities associated with an imperial mausoleum. All this is contained in a wall enclosure. In spite of its vast size the *Gol Gumbaz* is based on a very simple architectural form. Externally the body of the building is a big cube with a turret or tower attached to each angle, while between the elements, especially the ratio between the square mass below and the rounded portion above are excellent. The latter have no complex curves, it is merely an

immense inverted bowl. To these were added certain subsidiary forms which connect them as well as contribute to the architectural effect. Chief among the supplementary elements is the projecting cornice enriched by a closely set bracket. Above this is an arcade of small arches. Finally there are the bold foliation at the base of the dome, concealing the point of juncture with the drums, in a most appropriate manner. Below on this main wall-space three shallow arches have been sunk in each face. The larger archway in the center being panelled out so as to reduce it to the dimension of a normal doorway. These architectural accessories are not only in themselves work of art but are so disposed as to take their correct place in the composition. Thus producing a total well balanced effect.

The interior of the Gol Gumbaz consists of one chamber only, but it is a hall of majestic proportions. Like Pantheon of Rome and St. Sofia at Istanbul is one of the largest single cells ever constructed. The noticeable architectural features in this grand vaulted hall are the tall pointed arches forming the sides which give support to a circular platform above, provided to receive the base of the dome. The system of construction employed in this interior was as simple as its appearance. It begins with a square plan. This changes with rise in and finally a circle. This conversion of the square below into a circle above was achieved by ingeniously arranging each arch so that its feet stood with in the sides of the square plan, but with its plane of surface at an angle. The intersection above produces the eight sided figure on which the circular cornice was projected. The interior surface of the dome is set back some twelve feet from the inner edge of the circle. This way the proportion of its weight is transmitted directly downwards on to the four walls, the remainder being carried on the intersecting arches which also receive and counteract any outward thrust.

The dome itself is a plane plastered vault with six small openings through the drum and a flat section at its crown, but no central pendant. It is constructed of horizontal courses of bricks with a substantial layer of mortar between each course, in other words it consists of a homogenous shell or mono-block of concrete reinforced with bricks. All of this has an average thickness of ten feet. It seems unlikely that in the erection of this vast cupola, no centering of timber was used except for the section near the crown, as by the system of oversailing courses of brickwork scaffolding for such a purpose would be unnecessary. Bijapur builders were well versed in constructing the dome by means of a combination of intersecting arches. This method is almost unknown elsewhere. The only other instance is the sanctuary cupola in the cathedral of Cerdova in Spain, a building of Moorish origin but this is on quite a small scale.

The mausoleum of Mohammed Ali Shah is unquestionably one of the finest structural triumphs of the Indian builders. Considering its exterior dimensions, the total width of one of its square sides is equal to the entire height of the building. This is a little over 200 feet and the outside diameter of the dome is 144 feet. The interior of the hall measures 135 feet across and it is 178 feet high while the gallery from which the dome springs is 110 feet above the pavement. If the spaces covered by the various projections of the interior are omitted the entire area of the hall amounts to over 1800 feet. According to this calculation it is considerably larger in area than the Pantheon in Rome which measures 15,833 square feet. Thus the Gol-Gumbaz may claim to be the largest domical roof in existence.

Stone masonry was almost invariably used in the buildings of Bijapur, but in some of the palaces wood played an important part in their composition. It was used for pillars and in the construction of ceilings. This timber work was combined with a certain amount of stucco, so that in several of the halls these surfaces were decorated with mural paintings of the subjects executed in heavy but rich colouring.

Taking the production of these builders as a whole their masonry construction was one of the best in India. Some of their stone work being superb, almost equal to that of the best Roman. Then the brick work as shown in the execution of their domes, proves that they not only knew how to prepare their materials but also how to apply them to the best advantage. And as already explained, their system of intersecting arches was not only masterly but unique, arch structural process and practice implying long years of experiments in all branches of the building art.

5.9 Provincial Style, Kashmir

There can be few countries which exhibit more contrasting manifestations of architecture than the state of Kashmir. In the first instance there was the classical aristocratic and hierarchic development represented by the stone monuments of the Buddhists-Hindu period which flourished mainly during the first millennium. This was followed by the period of building in wood, as illustrated by the more democratic folk architecture, prevailed under the Mohammedan rule. Finally there was a short interval in the 16th and 17th centuries when the Mughal emperors brought into the state their own style of stone architecture. But the type of architecture associated principally with the Islamic domination of Kashmir is that constructed almost entirely of wood and which assumed a singularly distinctive form. In support of its ancient usage there is the evidence of the style of this wooden architecture

itself, which by the manner of its manipulation and its suitability to the climate and country and the need of the people proved that this construction method was regularly used from long time.

The technique therefore of the wooden work of Kashmir consisted in the elementary contrivance of laying one log horizontally on another, usually crosswise in the form of "headers and stretchers" as in the brickwork. In this fashion producing not only the walls, but also the piers for the support of any superstructure; in the case of any ordinary pillar however, single tree trunks were generally employed. A variety of Cedar tree, Deodar (*cedrus*, *deodar*) is the wood mainly used, and is floated down the rivers in the form of huge balks to its destination. The simplest method of such long construction may be studied in the series of bridges which span the river Jhelum at Srinagar, the capital city of the state. Several of these Kadals as they are called are still built on the cantilever principle, and illustrate a system of bridge building which probably been in practice for many hundred years. The main support or piers, that the form of a massive wooden structure, in general appearance it resembles an inverted pyramid with its truncated apex resting on a solidly built masonry. Each pier is built up of layers of logs in alternate courses placed transversely at right angles in such a manner as to make it sufficiently strong to withstand a fair flood current below and to carry a reasonable load above.

Wooden buildings in Kashmir were produced on the system as shown in Figure 5.22, for making the piers of the bridges. The architecture was even refined in better class of houses by filling the spaces between each course of squared log with neat brickwork on glazed tiles. The architecture of Kashmir is similar to the architecture of other mountainous countries specially to the Scandinavia. In the wooden church (Stavekirke) of Norway of the eleventh to the fourteenth centuries, there are the sloping roofs rising in tiers so as to form a kind of Pyramid, the sloping roofs rising in tiers so as to form a kind of pyramid, with gobbles and overhanging eaves. Each surface is made waterproof with layers of birch-bark. This has a resemblance with the wooden shrines of Kashmir. Further the chalets of the Austrian Tyrol with their projecting upper stories, balconies with carved railings and casement windows shows a familiar resemblance to the old houses of Srinagar.

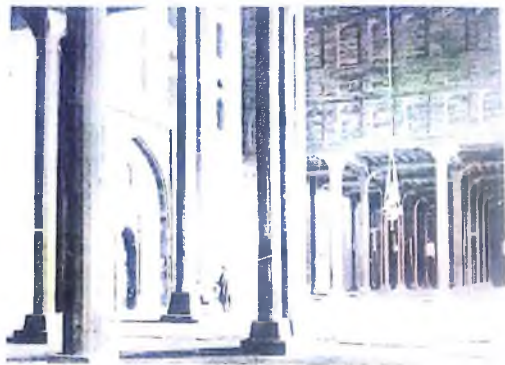


Figure 5.22 : Bridge, Srinagar, Kashmir, construction similar to the piers of the bridge [ASI].

This similarity is not due to some common origin between the countries so widely separated, but the similar climatic conditions and the same type of building materials available has brought this similarity.

Most important building in wooden style of Kashmir is the *Jama-Masjid* at Srinagar (Figure 5.23). This was founded by Sikande Butshi-Khan in 1400 and later enlarged by his son Zami-Ul-Abid. It consists of a square courtyard of 240 feet in diameter surrounded on all four sides with wide colonnades, the entire area is contained in all four sides with wide colonnades, the entire area is contained in all four sides within a exterior wall making a rectangle of 285 feet side retaining wall. This shows an enormous expanse of plane brickwork averaging 30 feet in height all round the building. The principal entrance is that on the south side and consists of a recessed portico. This leads to the colonnade forming the southern cloisters into the courtyard of the interior. Around the courtyard a continuous arched arcade is carried but in the center of each side the sequence of arches is interrupted by the imposition of a large structure of almost independence appearance. This has a square frontage containing an archway, while above this rises a pyramidal roof and steeple. Nave is reached after passing through the great archway which form the central feature of this sanctuary facade. The nave is a open space contained within a double range of tall wooden pillars with an arched *mihrah* occupying the interior wall. The real reppreciable conception lies in the treatment of its manifold pillared aisles and cloisters.

These lofty colonnades extend around the entire buildings, four aisles deep on three sides and three aisles deep on the fourth side. They are composed of ranges of pillars, each made out of a single *Deodar* trunk, varying from 25 feet to nearly 50 feet in height. There is much that impresses in the general appearance of this immense building, specially its proportions, dimension and the architectural character has made it an unique example in India. There are few structures dating from the early Islamic period which indicate that at one time the material from Hindu buildings was used for Muslim buildings. One of such conversions is a tomb in Srinagar (Zain-ul-Abidins mother) and was erected between 1420-1470 (Figure 5.24).



Figure 5.23 : Jama-Masjid, Srinagar, Kashmir, first construction 1-400, reconstruction seventh century [ASI].



Figure 5.24 : Tomb of Zain-ul-abidin's mother, Srinagar, Kashmir (1417-679).

This is one of the oldest Mohammedan building in Srinagar. The basement of this building is made from a Hindu stone temple of ninth century. In sixth and seventh century the Mughals have tried to revive the art of stone building in the state. There are three such examples: The fort of *Hari Parbat*, the *Pathar Masjid* and the mosque of *Akhun Mullah Shah*. All are executed in the grey limestone readily available in the valley. For this purpose the Mughal emperor Akbar has imported 200 Indian master builders as the local artisans were accustomed only with the wooden work.

In this fort, the *Kalti Darwaza* the *Sangin Darwaza* and the retaining wall are still of the Mughal period.

The two other stone buildings of the mughal period are of a slightly later date. *Pathar Masjid* date 1623 whereas *Akhun Mullah's* mosque dates 1649. Both the buildings show that the persons responsible for its erection were not influenced by the local wooden architecture of the valley. They have used their own materials and technique.

In addition to the fort and two mosques there are other structural records, mainly in brick masonry in this valley. For instance the large *Baradari* or pavilion in the *Shalimar Bagh*, a species of black stone pillars and sculptured brackets with every part in pleasing proportions and most artistically executed.

In spite of all this architectural impositions the indigenous style mainly composed of timber and is designed and constructed according to the tradition continued in its course.

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6. THE MUGHAL PERIOD

Five rulers of the *Mughal dynasty* were associated with the development of the architecture of this period, the emperors, Babur, Humayun, Akbar, Jahangir and Shah Jahan. But the *Mughal* style actually resolves itself into two main phases. Earlier phase in which the buildings were principally constructed of red sand stone during the reign of Akbar and in later phase white marble was largely used which suited the taste of Shah Jahan.

6.1 Babur (1526-31) and Humayun (1531-56 A.D)

During the earlier years of Mughal domination i.e. during the reign of Babur and Humayun, the country was too unsettled to produce any work of distinction. A form building art gradually emerged which represented this ruling dynasty. This in the course of time developed into one of the most important architectural styles in India.

6.2 The Mughal Period – Akbar The Great (1556-1605 A.D)

The type of buildings that came during this period were chiefly made in red sand stone which was readily available in these parts. The first example of his work is the fortress palace of Agra. One of its remarkable features is its massive enclosure wall. This consists of a solid sandstone rampart just under 70 feet in height and nearly on a half mile in circuit. This is the first application of dressed stone on such a large scale. This construction is of no little significance. It is said that “from top to the bottom, the fire red stone, linked with iron rings are joined so closely that even a hair cannot find its way into their joints”. Within the fortified wall at Agra are two gateways. The front consists of two broad octagonal towers joined by an archway (Figure 6.1) while the back is an elegant facade with arcaded terraces above, surmounted by cupolas, Kiosks and Pinnacles. Its dimensions allow a number of commodious rooms to form the interior, providing the quarters for considerable guards. From every point of view a most attractive appearance has been given to this structure by means of arcades recesses and other structural as well as decorative features.

Within the area enclosed by the walls of this fortress, one of Akbar's palace is still preserved. This palace was one of its kind to be erected. There is irregular symmetry of the halls and rooms. It seems that the Indian workmen were trying to adopt themselves to the new condition and to carry out a structural scheme with which they were not fully familiar. The result is that the Jahangiri Mahal (Figure 6.2) represents a state of transition between the Hindu type of Palace like Man Mandir (Figure 6.3) and the domestic requirements of a Muslim ruler in the 16th century. It is constructed throughout with stone but it contains several important features suggesting a wooden derivation. It is noticed from the figure that the shape and position of the brackets under the eaves, the inclined struts supporting the room beams of the northern hall and the pillar of portico would have been more appropriate in wood implying a legacy the timber age of building construction.



Figure 6.1 : Agra Fort; Delhi gate exterior (1566).



Figure 6.2 : Jahangiri Mahal, Agra Fort (cir. 1570).



Figure 6.3 : Man Mandir.



Figure 6.4 : *Jodha Bai's Palace, interior of northern hall (Fatehpur Sikri).*

The most notable architectural project of Akbar's reign after *Taj Mahal* can be seen in *Fatehpur Sikri*, which he has created as his capital. Akbar has not only constructed the religious buildings but also the secular ones. One of the most important buildings is the palace of Jodha Bai (Figure 6.4). The structure in this palace was so designed that each group of apartment could be readily divided off from others if needed. It was also arranged that the chambers below could be heated in cold weather whereas the chambers above always remain airy and cool.

Another example of these houses is the house of Birbal, the prime minister. There are cupolas over the upper rooms and pyramidal roofs over the porches. All of this is constructed on a modified principle of the double dome, as they have an inner and outer shell with an appreciable empty space between. By this means, the interior was kept cool.

Distinctive administrative building of *Fatehpur Sikri* is *Diwan-i-Khas* (hall of private audience). The main architectural object in the interior of

this hall is the central column (Figure 6.5). Its pattern shaft branched out into a series of thirty six close vaulted and pendulous brackets carrying the platform. It is most original conception and is not without artistic merit.

When Akbar returned back from his victorious campaign in Deccan, he erected *Buland Darwaza* (gate of magnificence, (Figure 6.6) at the entrance of *Jama Masjid* at *Fatehpur Sikri*. This gateway is a most imposing structure as its height is 134 feet. This is approached by a steep flight of steps 42 feet high so that the entire composition rises to a total height of 176 feet above the roadway. Across its front it measures 130 feet while from front to back it is 123 feet. Thus it presents from every point of view a mass of masonry of immense proportions and beating every other building in the city.



Figure 6.5 : *Diwan-i-khas, central pillar, Fatehpur Sikri (1570-80).*



Figure 6.6 : Buland Darwaza, Fatehpur Sikri.

6.3 Jahangir (1605-27 A.D), The Transition From Stone to Marble

Emperor Jahangir, son of Akbar patronized the school of miniature painting very enthusiastically. Whenever constructional work was planned, more frequently, it took the form of laying out large gardens and similar ornamental retreats rather than the erection of architectural monuments. So the building art in his reign was uneventful. In spite of his favor for miniature art, the main structure of one of the most important and remarkable buildings of the Mughal period was produced during his reign. This was his fathers mausoleum at Sikandra near Agra (Figure 6.7). This mausoleum encloses a big garden. In the middle of each side of the outer enclosure wall is a gate house. Three of these being false doorways, which have been added just for symmetry. On the south is the main entrance. These gateways seems to form miner monuments in themselves; particularly the one comprising the entrance. This is a structure of exceptional elegance. Because in addition to its pleasing proportions and bold inlaid ornamentation, it is provided with four graceful marble minarets, one rising above each corner. These minarets have almost no match and are significant of the architecture prevailed in the

reign of emperor Jahangir. Before this earlier phase of architecture under the Mughals merged into the later, one building was constructed, which may be regarded as the connecting link between the style of Akbar and that of Shahjahan. This is the tomb of Itimad-ud-Daulah at Agra (Figure 6.8). Enclosed with the walls this mausoleum stands in a garden with red sandstone gateways. It is a square in plan, its design comprising a central structure with broad octagonal towers in the form of minarets thrown out from each angle and a small pavilion or a type of upper storey rising above the roof. Three arched openings in each side produce an appearance of depth while cornices on brackets and a wide eave to the upper portion provide horizontal lines and shadows emphasizing the sense of quite peacefulness which pervades the conception as a whole.

As an example of architecture in miniature, this building with its accessories of garden and gateways is one of the most perfect of its kind. Its fineness is increased by the use of white marble of which the entire central structure is made. Ornamentation has been carefully done to the architectural effects. Most of the surface being delicately coloured by means of inlaid stones. The result of such treatment is that any undue brilliance of the white marble is subdued by the subtle tints of the inlay. Much of this ornamentation of applied stones was produced by a technical process different from those that existed before. So these later Jahangiri buildings not only mark a change in the architectural style but also in the method of decoration. Before this the inlaid work had been of the kind known as *opus sectile*, a marble *intarcia* of different colour, but from this time it took the form of *pictra dura* in which hard and rare stones such as lapis, onyx, jasper, topaz, cornelia and like were embedded in the marble in graceful foliations. The tomb of Itmad-ud-Daulah prefigured that phase of white marble garnished with gold and precious stones which distinguishes the final and most sumptuous architectural creation of the Mughals.

6.4 Shah Jahan (1627-58), The Reign of Marble

In the sphere of building art it was an age of marble. Thus the architecture become more impressive from this period. Marble specially of the textural quality as that obtained from the quarries of *Markrama* in Jodhpur (U.P.) state was mostly used. It provides its own decorative appearance due to its delicate grain size. The forms of this style are mostly in marble, while the decoration is occasionally plastic. Such enrichment was obtained by means of inlaid colored stones. This change in technique ensured a change in the larger architectural elements of the style. Particularly noticeable is the change

in the character of arch, the curves often foliated, usually in each instance by means of nine cusps.

With the result that white marble arcades of engrailed arches became a distinguishing feature of the period. The dome also assumed another form, the Persian type. The bulbous domes in its outlines with constricted necks found favor. The adoption of this brought with it the system of true double doming. Other developments were the introduction of pillars with tapering shafts, vaulted bracket capitals and foliated bases. Structural ornamental elements of a curvilinear order were added to this.

The replacements by the emperor Shah Jahan of the stone buildings in the palace, forts of Agra and Lahore by marble pavilion appears to have been carried out intermittently. For instance at Agra, the first of these marble halls to be built was *Diwan-i-Am* dated 1627 (Figure 6.7). This was followed some ten years later by *Diwan-i-Khas* (Figure 6.9), the double columns of which are among the most graceful of all those produced during his reign. At different intervals other marble palaces and pavilions were erected such as the *Khas Mahal*, the *Shish Mahal*, the *Nagina Masjid*. *Moti Masjid* is another creation of refinement. This mosque (Figure 6.10) building does not only show an unrivalled masonry of the material, but also the extent to which it may be artistically manipulated.

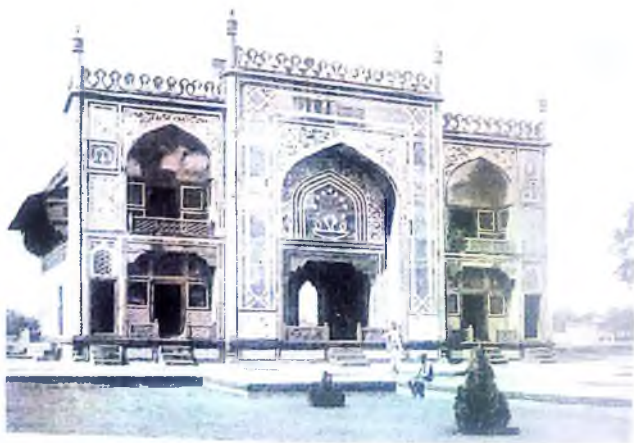


Figure 6.7 : Tomb of I'timad-ud Daula (begun 1628).



Figure 6.8 : Diwan-i-Am, Agra Fort.

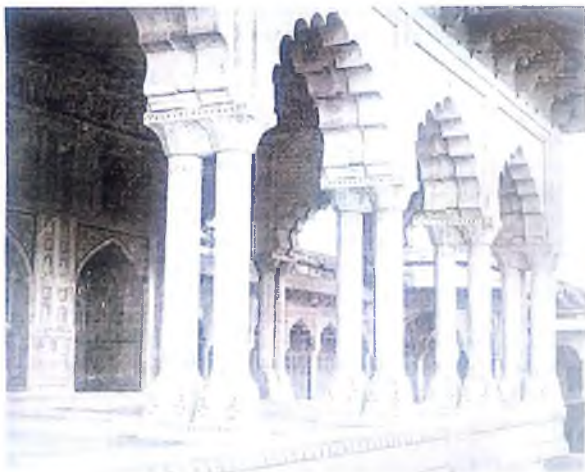


Figure 6.9 : Diwan-i-Khas, Agra Fort.



Figure 6.10 : Moti Masjid, Agra Fort.

Delhi has regained its lost status when Shah Jahan shifted the seat of the empire from Agra to Delhi in 1638. He began to lay out the city of *Shahjahanbad* on the right bank of the river *Jamuna*. Fourteen gates led into the city. Out of these only a few survived. Among these are *Ajmeri* gate in the southwest, *Turkman* gate in the south, *Kashmiri* gate in the north, *Nigambodh* gate in the northeast, and the *Delhi* gate in the south east. *Shahjahanbad* is crowded with historical monuments and this ancient city still survives much as it was, and is known as Old Delhi. The principal feature of this project consisted of a palace fortress for his own accommodation on a larger and more comprehensive scale than any previously produced. This formed a city within a city. This fort was constructed on the site of ancient *Indraprastha* (see section 2.1.10)

The fort's shape is irregular octagonal (Fig.6.11). Two beautiful gateways—the *Lahore* gate and the *Delhi* gate give access to the complex. The fort resolves itself in four parts; (1) A large central quadrangle containing *Diwan-i-Am* (hall of public audience), on each side of this are two square open spaces designed, (2&3) in the form of ornamental gardens and courtyards, while (4) is the range of marble palaces, one side facing the gardens and the other commanding an open view of the river. Included in this range of buildings, besides the palaces, were hall of private audiences and luxurious *hammam* (bathing establishments). Between each structure there were wide courts and terraces protected by perforated screens on rampart side.

Each of this structure is an open pavilion in one storey. Their facades are engrailed arches shaded by a wide eave or *Chhajja*. Above this rises a parapet and from each corner a kiosk. The interiors consists of engrailed arches in intersecting arcades which divide the whole space into a square each having a cornice and a flat highly decorated ceiling. These are no pillars, their place being taken by massive square or twelve sided piers, a formation which also gives a spacious soffit to the arches. In addition there is the ornamentation distributed over every portion, of gilt, color and inlaid patterns in sinuous scrolls and serpentine lines. Within the trecceried foliation's on the walls, piers and arches, conventional flowers like roses, poppies, lilies etc are freely introduced.

An important feature in the planning and arrangement of the palace portions was the provision of a full and continuous supply of water distributed throughout the entire enclosure. This was brought by means of a conduit called the *Nala-i-Bahisht* (canal of paradise). This entered the fort through a sluice and the *Shah Burj* (Kings Tower). Such a constant stream enabled the chain of gardens to be ornamented with fountains, cascades, waterfalls and pools. This has also furnished the gorgeous Hammams (baths) adjacent to the palaces with its requirement. One of the chief object of this supply was that it should be carried out by channels under and around the marble pavements of the royal pavilions so contrived that each apartment included all the accomplishments of a water palace.

The setting of fountain in *Rang Mahal* has added to its beauty. This besides being a gracefully ornate conception, accords perfectly with its architectural surroundings. It consists of a shallow marble basin sunk in the pavement, occupying the entire middle bay of 200 sq. feet side, the perfumed water bubbled up out of a silver lotus flower on a slender stem rising from the center. The design of the basin also represents a large lotus form of delicately modelled petals. This was contained within a square bordered frame. This fountain was one of the examples out of many in which the artists have shown their endeavour.

The remaining prominent structure in this royal portion of the fort is *Diwan-i-Am*. Although this is a sandstone structure, it seems that when it was made every part of the masonry was covered with an overlay of shale plaster and was ivory polished. The preparation of this exceedingly fine *Chunam* and its application being a technical process carried to a great perfection by the craftsmen from *Rajputana*. This has made this hall of audience outwardly in accord with the marble palaces with which it was connected. The entire complex of buildings, standing out in brilliant white, shows a significant feature of the interior of the audience hall was the

alcove in the back wall where the emperor sat in state. Here on ceremonial occasions the famous peacock throne was installed. The decoration on the walls of this alcove above the throne consists of a series of designs in *Pietra Dura*.

Emperor Shah Jahans building plans at Delhi were not confined solely to the creation of this fortress. *Jama-Masjid* at Delhi (Figure 6.12) is amongst the other structures, which are not less important from the architecture point. This mosque, the largest in India, is opposite Red Fort. It was built on a small hillock (*Hauzla Pahad*). The construction began under the superintendence of Sadullah Khan, Shah Jahan's Prime Minister.

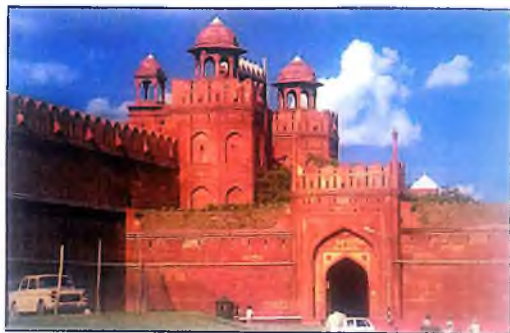


Figure 6.11 : Red Fort at Delhi.



Figure 6.12 : Jama Masjid at Delhi.

Ustad Khalil was the architect. The chief feature of this mosque is its symmetry. It has three gateways-in the north, south and east-each approached by broad flights of stairs. The most imposing gateway, formerly reserved for use by the Mughal emperors, is shaped like an irregular octagon and has three storeys. The three gateways open onto a large courtyard paved with red sandstone. On the west side of the court is the mosque surmounted by three marble cupolas with copper spires and inlaid with vertical stripes of black marble. The central dome is the largest. On either side are two elegant tapering minarets composed alternately of vertical stripes of white marble and red sand stone. Each minaret has three projecting galleries and a number of steps topped by an octagonal pavilion with a dome of white marble.

Within the mosque is a small room built of wood. This room contains a few relics among them the *Quran* transcript by Imam Hussain.

During the same period that the buildings in stone and marble were being erected in the principal cities of the Mughal empire, in the northern part of his dominions another architectural expression took the form of sandstone for additional strength. Its chief characteristic was the exterior decoration. This covered most of the surfaces which consisted of patterns in brilliantly colored glazed tiles. For instance Wazir Khans Mosque (Figure 6.13) in Lahore. These bricks and tiles decorated buildings aided by their environments and the ever present sunshine, display all the characters of a determinate style. This tile decoration takes two forms, one in which the tiles are about six inches square having the design carried across the joints so as to present the effect of a "free all over" pattern. Another system in which the tiles are much smaller and are cut in the shapes of the pattern unlike mosaic. These are called mosaic tiles. The former kind was somewhat rare, whereas the later one is more common. The mosaic tile process was practiced only in Persia and northern India, where in the sixteenth and seventeenth century it was evidently an important art industry. The substance of the tile was not the clay but its basis appears to have been composed of disintegrated sandstone ground to a powder. This when fused under certain condition form a kind of crude porcelain of a whitish color, giving transparent quality to the glaze. Each piece of the design was cut in a manner like the pieces of a jigsaw puzzle and then cemented into its required position in the design.

The tomb of Asaf Khan at *Shahadra* (father-in-law of Jahangir) bring to notice another exotic feature, in a portion of its decorative treatment. The tomb building itself stripped now of its marble facing, in spite of such disfigurement, has every appearance of having been a handsome structure.

and still displays, on its exterior specimens of rich mural ornamentations of tile work of the kind referred to above. But it is in the interior chambers that an exceptionally fine plastic work has been applied. For here on the ceiling, are the remains of a graceful interlaced pattern in high relief, executed in plaster and attached to the concave surface by means of a framework of bamboos.

The manner in which it is manipulated and its appropriateness for its purpose are all definitely worthy of praise. But all these architectural experiences stay in the background when compared with that materialized vision of loveliness known as *Taj Mahal* (Figure 6.14). This is the mausoleum of the emperor Shah Jahan's beloved consort the empress Arjuad Banu Begum, who titles *Mumtaz Mahal*. This work through out was wholly indigenous. Much of the charm is produced by the quality and texture of the material used in its construction. This marble from *Markarana* is of such a nature that it takes incredibly subtle variations of tint and tone, according to the changes in the light, thus picturing the passing color of the moment. Especially it is noticeable in the shadows which on occasion are almost as delicately in perceptible as those cast upon clear water, soft but still giving the definition and depth. For every hour of the day and for every atmospheric condition the *Taj Mahal* has its own color values. It ranges from the soft dreaminess at dawn to its cold splendour in the moonlight, when the dome thin of substance as the air, hangs, among the stars like a great pearl. None of these effects can equal those few fleeting moments when softly illuminated by the brief Indian after glow, it assumes the enchanting tint of some pale and lovely rose.



Figure 6.13 : Wazir Khan's Mosque, Lahore.



Figure 6.14 : Taj Mahal at Agra.

6.5 Aurangzeb (1658-1707 A.D) (Concluded)

Aurangzeb was the last of the “Grand Mughals”. This has created the decline in the building art. The building construction during his time was not of great significance. He stayed for a longer period in the south (Deccan) and made the capital of his territory at Aurangabad. At one time it was known as “Delhi of the south”. In this city of Aurangabad still are the remains of a citadel and other architectural records of one time royal seat. A mausoleum of the wife of the emperor (*Rabi Daurani*) is still preserved. The design of this was inspired by Shah Jahan’s Taj Mahal. Other erections of his period are *Badshahi Masjid* at Lahore (Figure 6.15) a mosque at Benaras (upper India), *Jama Masjid* at Mathura.

After the death of Aurangzeb in 1707, the collapse of the empire was a matter of time. The few buildings in the Mughal style that were erected after his death are a proof of the decadent conditions that then prevailed. Due to the political circumstances the political power was transferred to Lucknow from Delhi, where the Nawabs of Awadh became paramount. The mausoleum of Safdarjan (1739-53), a nephew of the first Nawab of Awadh is the last of the muslim monuments of note to be built near Delhi (Figure 6.16).



Figure 6.15 : Badshahi Masjid Lahore.



Figure 6.16 : The Mausoleum of Safdarjung.

This is erected near the mausoleum of the emperor Humayun (the first royal Mughal) tomb to be built in India. The contrast between the two monuments the initial and final, erected at an interval of 200 years is very instructive. These Nawabs were defatigable builders. This was the stage when the source of inspiration was ceased and the stagnation begun. This state of decadence may be due to the fact that the art appears to have reached that point at which all the essential problems of construction have been solved and when the major elements of the style had been brought to perfection. Thus no further progress was possible.

In these circumstances the workmen found that the only hope of advance lay in the direction of the repetition to a larger scale of that which had already been brought to the highest degree of fulfillment. To achieve this they discarded the use of stone or marble and reverted to a brick and rubble foundation faced with stucco. Thus they could produce the architectural projects of great size with imposing appearance but at considerably less cost and in shorter space of time. It should be added that in the manipulation of these materials, the workmen showed exceptional technical skill. The finished execution of the ornamental details and moldings in plaster being the redeeming feature of this phase of the style. These skills are very distinctly seen in the architecture of Lucknow.

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7. FORTS AND FORTRESSES IN THE WEST COAST OF INDIA

There are as many as 463 forts and fortresses in Maharashtra, a state in the west coast of India. Forty eight of them may be called the premier forts with strong well fortified structures which could well stocked with provisions, withstand a long siege. In fact many of these main forts are so strong that they could be captured only by deceit or bribery. The secondary forts (37) are also strong but their main function was to support the main forts and to extend their range of command and control. In addition, there are 378 fortified outposts. These could not withstand a long siege. Fortification of Pratapgarh fort is shown in the Figure 7.1



Figure 7.1 : Bastioned walls of the Daulatabad fort. [S.Gill, India Perspective, January 2001].

Though most of the forts are in disuse today, yet the shell marked ramparts and battlements, massive towers and gates give an idea of their majesty. These forts played a major role in a titanic struggle which took place in the region some 350 years ago. Shivaji, the son of a minor chieftain, took up arms against the powerful sultan of Bijapur and the even more powerful Mughal emperor. The mountainous terrain, which was covered by thick jungle, provided the ideal ground for gorilla warfare in which he excelled. His army of peasants armed with bows and arrows and slings routed the well equipped armies of his adversaries. The foundation of Maratha empire which spread to large areas of north India in the 18th century was laid in this part of the country.

There is an interesting tale about Shivaji and his forts. At the beginning of his effort to establish an independent kingdom. Shivaji, it is said lost his ways. He was caught in a heavy shower and took a shelter in the hut of a peasant. He was not recognized. The peasant's wife served him rice and lentils for dinner. As she poured the lentils it began to run around. The women laughed and said "You are as foolish as Shivaji". He asked "Why do you call Shivaji a fool ?. The woman replied "He captures the land but has to give it up when the enemy comes in force. He does not know that he has to capture the forts. This will ensure his control of the land. Similarly you do not realize that if you want that the lentils should not roll off, you should make a depression in the rice and take the lentils there."

Shivaji realized that there was truth in what the simple peasant woman had said. He started concentrating on forts. When he captured them he took particular care to strengthen the century old forts. Those that he built himself bear testimony to his attention in detail. The fortification of the fort looks similar to the China wall (Figure 7.2). The site for a fort was selected from the point of view of its defensive value. An assured supply of water independent of the countryside was a basic criteria. The gate were surrounded by towers so that they could not be opened by a frontal attack. In many forts, it is only when one comes very near that one realizes that what he mistook as two rock projections were in fact towers guarding the main gate. The pathway from the main gate to the interior part of the fort gradually narrowed so that even if the enemy entered the main gate, he could only send two or three soldiers ahead and a small force could stop them.



Figure 7.2 : Fortification of Pratapgadh fort [S. Gill, *India Perspective*, January 2001].

Shivaji built many forts but the pride of place goes to Raigad (the Royal Fort) which he subsequently made his capital and where his coronation as an independent ruler took place. The English scholar Thomas Nicols, after a study of the fort, has said that if the fort was well provisioned, a small garrison could hold it against the whole world. It was aptly described by the British as the Gibraltar of the east as it held on for a long time after the other forts had been captured by the East India Company in 1818.

In many respects Raigad was an architectural marvel. There were stone pipes for the sludge to flow out. There was no such arrangement in the palaces built by the Mughals in Delhi or Agra, or even in the European capitals. Shivaji's instructions about the maintenance of forts read like a modern day manual. The keepers were ordered to remove the shrubs and wild growth from the mountain before the rains as their growth in the rainy season could provide support to an attacking force. Repairs too had to be carried out. Surprised checks were done to ensure that the instructions about safety of the forts were meticulously followed.

It is said that once he appeared at the gate of a fort after sunset and asked the gate to be opened as an enemy force was pursuing him. The keeper of the fort refused but assured the King that his muskets and guns would give him full protection against the enemy. He lowered a cot and bedding for the ruler, and told him that a neighboring vigil would be kept to see that no harm came to him.

Tales and legends are associated with almost every important fort of Shivaji. There is Simhagad (The Lion Fort) near Pune which was captured by Subedar Tanaji Mallusare, his boyhood friend, who climbed the steep wall of the fort with small group of soldiers, fought his way to the main gate and opened it for the Maratha army waiting outside. In process, he lost

his life. On hearing his death, Shivaji remarked "The fort has been taken but the Lion is no more". The fort till then known as Kondana, came to be known as Simhagad because of the supreme sacrifice of Tanaji. The massive gateway to Simhagad fort is shown in Figure 7.3.



Figure 7.3 : The gateway to the Simhagad Fort [S. Gill, India Perspective, January 2001].

The last of the Mughal king Aurangzeb invaded the tiny kingdom after Shivaji's death, killed Shivaji's son Sambhaji but found it impossible to fight guerilla tactics of the Marathas. Shivaji's younger son Rajaram took shelter in the fort of Jinji, a thousand miles to the south and directed the operation from there. Shivaji had captured the Jinji fort and strengthened its defenses just for such an eventuality.

8. STEPWELLS OF GUJARAT, ARCHITECTURAL MARVEL

Gujrat is home to hundreds of step wells scattered throughout the state. In fact, constructing a well was held to be a pious deed that absolved one of his sins and certainly earned more merit than the sacrifices for the builder. Almost each village or town boasted of at least one *vav*; for centuries, these *vavs* served their purpose. To-day many of the *vavs* have withered with time while others are in disuse as villagers prepared to move in search of greener pastures. However, some of the *vavs* have survived as structures and continue to supply water while some are venerated for their spiritual presence [Makhfi, 2001]

A typical well is made up of *Mandapa* or the entrance pavilion which forms the main approach at the ground floor level (Figure 8.1); the *Kuta* or the flight of steps leads down to the water or *Kund* at the bottom. Most of the wells are decorated with sculptures on all available surfaces (Figure 8.2). It is not only the works of art which is marvelous, the science and engineering skills with which so many pillars and lintels are made to support the five or seven storeys and that too with everything under the surface of the earth is amazing.



Figure 8.1 : The Mandapa, Entrance of the “Adalaj Vav, [S. Perveen, India Perspective, January 2001].



Figure 8.2 : The sculpture at each storey of the Vav. [S. Perveen, India Perspective, January 2001]

8.1 Navghan Vav and Adi-Chadi Vav

The earliest among the stepwells in Gujrat are nested among the Junagarh hills-Navghan Vav and Adi-Chadi Vav. The two stepwells appear to have been patiently carved out of soft rocks and these suspensous projects have been excuted to great depths. However, in the long list of structurally created step wells one has to revert to Dhank where sixth century Jhilani and Manjushri vavs can be seen. Almost after five centuries another stepwell was constructed near the famous sun temple at Modhers. The lateral formation of steps is punctuated with a number of miniature shrines at all levels. (Figure 8.3)

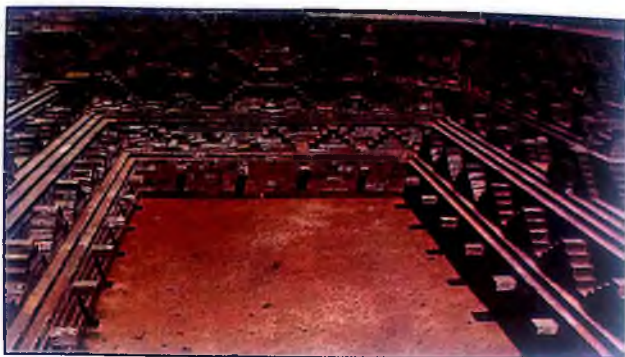


Figure 8.3 : Suryakund at Modhera [S. Perveen, India Perspective, January 2001]

8.2 Rani Ki Vav

Rani ki Vav in Patan is the most magnificent of all stepwells created in 1032 AD by Rani Udayamati. She was the queen of the most powerful Chalukya king Bhimdeva whose reign is marked with manifold building activities. A greater part of this vav remained buried for years while the exposed portions were dismembered to embellish another stepwell- *Bahadur Singh ki Vav* in the same village. Though in ruins and dilapidated to great extent, the remaining part of *Rani ki vav* continues to impress for its grandeur in dimension and profuse ornamentation.

Almost the entire Hindu pantheon seems to have been chiseled on the walls of the well, besides the sculptured niches and corridors that gradually diminish as the well draws nearer at a depth of nearly 285 feet. *Vaishnava* sculptures depicting Lord *Vishnu* in various forms can be seen. The most pictorial among them is one that shows him reclining on the couch of *Sheshnaga* (Lord of Snakes). Female figures: *Apsaras* /*Devanganas* / *surasundaris*) are in abundance. Possibly they are the best symbolic representation of the reproductive powers of nature. For instance, a scene depicts a *devangana* standing under a mango tree, holding her left breast which suggests fertility and maturity just like the mango and the mango tree. Often female forms have been visualized with a mirror, pitcher or carrying a child or simply emulating dance forms.

In decorating the *Rani ki vav*, the craftsmen appear to have been given a free hand to play with their imagination (Figure 8.4). Some of the sculptures can be interpreted as religious and they are often compared to sculptures in Modhera sun temple, Buddhist *Stupa* at Sanchi, *Vimala Vasahi* temple of Mt. Abu and even *Khajuraho*. Some of the images are erotic conjunctions. The artists have also included combats, weapons and warriors confronting opponents in the shape of man or animal.



Figure 8.4 : Figures adorning the walls of Rani ki vav [S.Perveen, India Perspective, January 2001]

8.3 Sabarlings Waterways

A little distance from *Rani ki vav* are some outlines of medieval waterways. It was early 12th century when Jayasimha Sidha Raja excavated artificial lakes. The largest among them was *Sabasarlinga* Tank which must have been an immense reservoir, as is evident from the surviving remains of the brick embankments and the giant sized sluice-ways. In the nearby museum one can see the various statues recovered while excavating the *Rani ki vav* and the *Sabasarlinga* waterways.

8.4 Mata Bhavani Vav

Mata Bhavani vav, in Asarva, on the outskirts of Ahmedabad, is another stepwell assigned to the Chalukyan period and dedicated to Amba Bhavani (Names for the mother Goddess). It is noted for its significance rather than its architectural appeal. The well is simple and modest in make with minor ornamentation in the galleries leading to the stretch of steps that travel down to the pool of water. However, some pre-medieval carvings and sculptures can be admired on the parapets that house the canopied roofs, niches and friezes.

8.5 Dada Harir Ki Vav

Asarva is famous for another stepwell popularly called *Dada Harir ki vav*. This *vav* brings us to the early 16th century reign of Sultan Mehmud Begarah (1458-1511), the most outspoken among the Gujrat Sultans.

Bai Harir Sultani was the superintendent of the royal harem and she had planned the *vav* along with her mausoleum and mosque amidst a sprawling garden interspersed with fruit bearing trees. The *vav* is reached through a flight of steps that remain uniform through out the descent. The pool at the bottom leads to the shaft of the well which is divided by an arched doorway. Besides, there is a narrow spiral stairway leading to the well. Being a Muslim monument, it is bereft of figurative decorations, which have been replaced with floral motifs. The Hindu influence is evident from a few animal figures. Inscriptions in both Sanskrit and Persian tell us about the cost of construction which 329,000 *Mahmudies*- gold coins of the Beghara era. Besides other details and obeisance to the creator, the epigraph reads " this well was built at a place where four roads meet, crowded with good men, who come from four quarters. As long as the moon and sun endure, may the sweet water of the well be drunk by all men." However, the water in this *vav* has dried up over the centuries.

8.6 Adalaji Vav

Adalaj Vav is situated 18 km from Ahamdabad. It resembles closely to *Dada Harir vav* in its size and lay out but is richer in ornamentation. The inscriptions to *Adalaj vav* suggests the construction cost to be five lakh *tankas*. The numerous pillars that hold each storey of the *vav* are profusely decorated with fine details, and so are the balconies and niches. The ornamentation here is of mixed nature. The Hindu motifs are prominent but the floral and geometric patterns popular among the Muslims are also seen.

8.7 Helical Vav

Helical vav in Pavagarh is another interesting and unusual well attributed to *Visvakarma Vastushastra* where the entrance staircase leads to a spiral stairway which further culminates into the well. In fact the spiral stairway gradually becomes the wall of the well and a timid soul should avoid these steps that make one dizzy with the sight of the water getting closer with each step.

At Wankaner Palace one finds a more recent stepwell (1935) built in sandstone but worked out with a marble surface. It reflects the palatial outlook and the purpose was simply to provide a summer escape by lowering the temperature down below.

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9. ARCHITECTURE OF LUCKNOW

9.1 Historical Background

Lucknow lies on the bank of the river Gomti in the northern part of India. It is the capital of the state known as Uttar Pradesh (U.P) (Figure 9.1). Not very much is known about the history of Lucknow. However, according to the legends and myths it is locally believed that Lucknow was ruled by Lakshman, the younger brother of Lord Rama, the king of Ayodhya who has named it Lakshmanpur after the name of his brother. Besides these legends the earliest historical account about Lucknow is mentioned by Ibn-Batuta in his *Safarnama* (1338-1341), by Abul Fazal in *Ain-e-Akbari* and by Gul Badan Begum in *Humayun Nama*. Lucknow got the prominence when the Mughal emperor Akbar (1556-1605 A.D) divided the whole India into 12 provinces and Lucknow was chosen as the seat of *Subedar of Awadh*, which is known as Uttar Pradesh to-day (U.P).



Figure 9.1 : Map of Uttar Pradesh.

Sheikh Abdur Rahim, a noble man of Bijnaur (in the state of U.P.), was entrusted with the *Jagir* of Awadh. His tomb known as “Nadan Mahal”, is the oldest monument of Lucknow. After Sheikh Abdur Rahim, Lucknow became the paramount power under the Sheikh families till Mohammed Amin stepped in as Subedar in 1720. He has made Faizabad as the capital city instead of Lucknow, where he was declared as Nawab. In 1740, the Nawab was also called as Wazir, and thereafter he was known as the Nawab Wazir. But most untoward incident happened when Nawab Shuja-ud-daula was defeated by the British at Buxar in 1764 which forced him to enter into a treaty with the East India Company. This was the beginning of the Britishers feet on the soil of Awadh.

In 1774 as a result of this treaty Shuja-ud-daula agreed to have a British Resident stationed in Awadh. In 1775 Asaf-ud-daula, son of Shuja-ud-daula shifted the capital of Awadh from Faizabad to Lucknow. Although the court of Nawabs flourished at Lucknow, but the real power came into the hands of British Resident stationed at Lucknow. The Britishers annexed Awadh in 1856 after exiling the last ruler, Nawab Wazid Ali Shah. As a result of these preceding phases of history (Mughal, Nawabi, British) Lucknow experienced a unique architectural amalgamation in the form of a variety of monumental structures such as Mahal, Immabara, Maqbara, Masjid, gates, bridges and the colonial buildings of the successive rulers.

9.2 Building with Bricks and Stuccos

In the Mughal period, it was popular to build in marble but in the places where there was scarcity of marble imitation was done with bricks and stuccos. Bricks and stuccos were the normal building commodities, but there was no standardization of the bricks or the mortars to be used. It depended upon the supervisor on site. There was a big gap between the theory and practice amongst the artisans. This deficiency was very distinct and has attracted the attention of many people. For example Thomas Williamson [Fatal Friendship, 1985] in 1810 wrote:

“Some of the *Rauz*, or bricklayers, in India, are very clever, so far as relates to mere practical operations; but they have not the smallest idea of planning from paper, or on paper”.

It was seen very often that one person can do the work of bricklayer, carpenter and blacksmith. They were guided solely by the supervisor to do the job. No matter then how precise the architects intentions are, ultimately it was upto the supervisor on the site to ensure that the plans were carried through, or to adopt the plans to the abilities of the work force and the materials available.”

In spite of the ignorance of the theoretical knowledge, the masons were gifted with the empirical knowledge which they have got from their forefathers. This being the living bread there was no documentation of the material and technique. The science passed through the hereditary. This is the reason why the knowledge about the materials and their application technique which was so successfully used in the ancient period is successively disappearing.



Figure 9.2 : An arch made of lakhori bricks near Karbala, Talkatora, Lucknow [Photo, Chandra, 2000].

9.3 Lakhauri and Pan Patta

It is of great interest to look into the materials and the way they were used in Lucknow. This speaks about the intelligence and the vision of the supervisors controlling the work. The most common materials used were baked bricks and stuccos. It was used in building the houses of well to do persons; the Nawabi palaces and the religious buildings. A structure made of baked bricks, i.e. bricks that had been kiln fired, was called “*Pukka*”, while the building made of sun dried bricks was called “*Kutchra*”. The bricks used were called *lakhori*. These *lakhori* bricks were only 3/4th

inch thick, and 4 by 6 inches in length and breadth. There were also thicker and heavier bricks (2 inches thick) known as *Pan Patta* or *Ilamsi*, after the name of Ilmas Ali Khan, Deputy Governor of Awadh during the time of Saadat Ali Khan, who reputedly used these bricks in his own buildings. There is also a series of curved bricks, which make up the elaborate balustrade of the second floor, and the triangular bricks used to build up the core of the statues. The great advantage of *lakhori* bricks is that they can be used both with *pan patta* bricks and also by themselves to form remarkably fine details even before any stucco is applied. This is seen in one of the huge arch near *Karbala* (Figure 9.2). Small *lakhories* were used for giving the desired shape. It is also seen that the mortar used to join the bricks is very little. Besides getting the desired shape, *lakhories* give high strength to the structure compare to the big bricks.

The more skillful the bricklayers the less coarse work was there for stuccadors, who could concentrate on delicate work instead of covering the vast area with stucco to imitate the stonework effect. The masons were perfect in imitating the stone work one of the example is seen in the gallery pillars which are made of bricks and stucco, but resembles stone structure (Figure 9.3).



Figure 9.3 : Pillars made of red lime mortar, imitating the stone structure, [Photo, Chandra 1999].

9.4 Chunam and Surkhi

Besides using the whole bricks these were also milled and used as one of the constituent of the cementing material. This pulverized bricks was called *Surkhi*. It is a pozzolanic material. The other constituents varied depending on whether the mixture was to be used solely for joining the bricks together, or for coarse plastering over the walls, or for the floors and roofs of buildings (when it was known as *tarras*) or for the final coating over the walls. The *Chunam* (which is often translated as lime), but which should be rendered as stucco had the cementing properties. The properties of lime of course depended upon the materials used to produce it. In south of India, Madras, a very high quality of lime was produced by using pulverized sea-shells, but this was so expensive that it was seldom used in northern part; Uttar Pradesh or in the Eastern part; West Bengal.

Lucknow masons believe that the stucco in the Jama Masjid was made from red lime (*Kankar lime*), gum, a kind of fine pulse called "*Urad ki Daal*", Jaggery, shells and a sticky paste called *Saras*. These organics are described in detail in the chapter "Plasters and Mortars" in the second part. The composition of *Chunam* could vary considerably according to the pocket and the taste of the builder. The *Nawabi Chunam* of Lucknow was especially commended upon and a few examples of marble like *chunam* remains, for instance in the Residency Banqueting Hall. However, *chunam* in other parts of India like Udaipur and Jaipur in the state of Rajasthan, where marble is mostly used, is consistently better preserved and is of highest quality.

Stucco could be used to produce effects in quite deep relief, even when applied to a flat wall, as in the pediment on the Husainabad well where figures in Graeco-Roman style are molded to produce a two dimensional effect without relying on a skeleton of brick or iron. Similarly the false domes which appear on the walls of the Safdar Jang tomb in Delhi, the Great Imambara, and the Residency complex Begum Kothi in Lucknow, and are very characteristic of the eighteenth century *Nawabi* architecture. These are built in stucco to a smooth wall and not built up over a brick core.

As already mentioned there was scarcity of stone near Lucknow. Thus the buildings where the stones were used are rare, and speaks about the status of the owner. Only two buildings are recorded that were constructed entirely from stone-the *Sungi Dalan* in the *Macchi Bhawan* complex and the *Lal Baradari* in the *Chattar Manzil*. Although this latter building is now painted red outside and could easily be mistaken for a brick and stucco

structure. It is in fact made from Jaipur marbles. Most of the stones used in Lucknow were brought from *Chunar*, a town to the south east of Lucknow. Claude Martin's inventory for constantia mentions 363 slabs of Chunar stone for use in the House and in 1841 Colonel Wilcox speaks of the immense stones which were brought from Chunar for the piers erected in his observatory. Various uses of marble in the interiors of buildings were recorded though very few remain. Only two carved marble fountain basins are noted; the first taken from the palace of Zahur Baksh and presented to Lucknow Museum in about 1988 and the second of fine white marble with a black inlay in the banqueting hall of the Residency complex. The large tank in the center of the *Chattar Manzil* complex was of marble, as were the baths in the *Badshah Bagh* on the north bank of river Gomti. Marble floors were found in some of the most elaborate buildings, including the white marble floor inlaid with a mosaic work of black and red which was laid over the heated flues of the *hammam* or the bath house in the *Masjid Bhawan* complex. It is probable that this was the floor referred to in a new paper report of 1792 which says;

"The prince of Awadh (Asif-ud-daula) has given an order to a very eminent and ingenious artist in this country (England) to prepare him flooring of marble etc for a smoking room. The order is completed, and is the first thing of the kind that was ever made in this country. It is 20 square foot, and is composed of more than 8000 pieces. In this flooring are introduced all sorts of marble which are arranged with a taste and judgement that do infinite credit to the artist".

Besides the bricks and Nawabi stuccos, pottery was extensively used, not only for flow of hot air from the lower rooms to the vents in the flat roofs but also for decorative purpose. The potters have imitated balusters in clay and many still survive, especially on the roof parapet at the *Asafi Kothi*, and for garden walls at ground level. A more beautiful use of pottery, and the one very peculiar to Lucknow was for the roof finishes and the ornaments. These were carried out in a green glazed ware, produced by adding copper to the glaze, and when placed in the position along roof parapets and towers produced a striking effect. Of those still in existence the commonest types are the "*pineapple*" and the "*Guldasta*", a cluster of flower buds. Both these type of ornaments can be seen; first at *Kakori* and *Mahmudabad* and the second at the Captains Mosque in the *Daulat Khana complex*. Early pictures of *Rumi Darwaza* show a whole series of *Guldastas* around the arch which are believed to have been originally fountains throwing jets of water up from the heart of each *Guldasta*. A more specialized use of pottery was made in producing small clay medallions, now found only in La-martiniere in Lucknow.

9.5 Construction of Typical Nawabi Pukka Building

The erection of a typical nawabi *pukka* building was a slow process, first a deep foundation had to be dug, not just because of the soft and friable nature of the soil and the weight of the proposed superstructure, but because the basement or the semi basement rooms embedded in the soil were valuable as retreats during the summer season. These rooms, the *tykhana*, had a small downward pointing shafts near the ceiling to provide light and air, but not directly sunlight. The floors of such basements were of considerable thickness, constructed of the layer of bricks and cement with flues inserted at regular intervals for drainage, although two rows of inverted pots were sometimes substituted, packed round with sand or coal, which was then covered with a layer of tiles and cement. Wooden beams were not used at all at this level because of the fear that the imperfect drainage may damage the wood in *monsoon* period.

All the walls were made of solid masonry of enormous thickness. The partition walls were even 2 feet in breadth. These are composed of solely *lakhauri* bricks and cement. Some solid walls in Constantias measure five feet across. They are built of solid masonry, with no rubble core. The only exceptions are the outer walls of Constantia and Barowen which incorporated pottery ducts as air-cooling devices cemented into the walls.

Over the beams were placed wooden joists or battens of thinner wood, and across these joists were laid flat pottery tiles, cemented in place. Normally two layers of tiles were used each sandwiched with cement. Then 4 to 5 inches of rubble or mortar was laid on top of it before the final coat of mortar was laid, which would then in turn be stuccoed over and polished. Conventional wooden board floors were seldom used because the underside of the boards would not be visible for visual inspection of damage due to white ants and the damage because of warping. Most buildings were of no more than three complete storeys, including the semi basement, though they often incorporated a smaller fourth storey over the center of the building, as in the Dilkusha, and Constantia has six storeys.

Once the masonry had been completed wooden lintels and frames were inserted where appropriate, and doors, windows, and shutters were hung, and were invariably painted green. Some prefer all verdigris, other, a deep clear green for the framework, with verdigris for several leaves or valves. Windows were normally made of glass as it was cheap, and readily available in Lucknow. Inside the building were the circular staircases, always surrounded by a masonry stair-well.

Even the building as palatial as Asif Kothi continued the tradition of small staircase. Until 1780 most staircases were built in masonry, but wooden staircases then came into use. These rest on strong wooden beams, all joist were painted or tarred. Many nawabi buildings have iron rings near the ceiling level, both inside and outside, where cloth could be hanged. It functioned as a fan which was operated manually. These *Punkhas* (fans) were attached to the ceiling beams by iron rings. The verandah roof at Bibiapur still remains part of the wooden *punkha* frame.

Inside the house, after the walls had been stuccoed and the ornamental moldings made, delicate colors like lilac and sky blue were applied, often with the molding and beading of the mock door panels picked out in white. Many nawabi houses still retain conventional European fireplaces with wide flues, but one must conclude from the complete absence of the chimneys at roof level that such fireplaces were purely decorative or, what is more likely, that they held movable braziers of charcoal during the winter.

9.6 Monumental Heritage of Lucknow

The monumental heritage of Lucknow is best reflected through a magnificent variety of edifices belonging to the Mughal, Nawabi and British Period [Fonia, 2000].

9.6.1 The Mughal Period

Nadan Mahal

Nadan Mahal is the earliest monument of Lucknow built during the Mughal period and thus holds a special pride. It is situated at Ahyaganj, between Raqabganj and Nakhas on the Nadan Mahal Road. It is built in red sand stone. Locally known as the tomb of Sheikh Abdur Rahim, the Subedar of Awadh during the reign of Mughal emperor Akbar (1556-1605 A.D). It was constructed by his wife. The entire monumental complex consists of three structures named as Nadan Mahal, *Sola Khamba* (sixteen pillars) and the tomb of Ibrahim Chisti.

The Nadan Mahal: the meaning of which is a place of etherial peace consists of a domed chamber that is surrounded on all sides by a verandah. the main chamber of tomb contains the graves. The verandah possesses four columns of Mughal style on each side, in addition to those at the four corner of the tomb. The brackets supporting the projecting *Chajjias* are decorated with animal figures and the moldings (Figure 9.4).



Figure 9.4 : Nadan Mahal, [Photo, Chandra 2000].

The dome is crowned by columns leaf finial base rises from a low octagonal drum which stands on a square pedestal and ornamented plaster. The roof is reached through a narrow stair case in the right side of the entrance wall. The roof of the varandah is covered by sand stone lintels. The floor of the masouleum is designed with marble inlay work in floral and geometrical patterns which contain two marble graves among which the Sheikh's tomb is placed in the center. The other grave by his side is of his wife's.

The Sola Khamba (Sixteen Pillar): It is an open pillared pavilion built of red sand stone. It is 10 m x 10 m in length and breadth and stands on a raised platform. The columns and the brackets are similar to the Nadan Mahal tomb and the corner brackets are ornamented with elephant headed design. The parapet is also of sand stone and elegant designs are carved over it. The floor of the platform is of red sand stone bordered by a frieze of plain and elongated stars. There are five graves in the pavilion, the ceiling of which is carved in a conventional pattern (Figure 9.5).



Figure 9.5 : Sola Khamba pavilion at Nandan Mahal, [Photo, Chandra 1999]

The tomb of Ibrahim Chisti: father of Sheikh Abdur Rahim lies at a short distance from the Sola Khamba. It is a domed building built of *kam* blocks (Figure 9.6).



Figure 9.6 : Tomb of Ibrahim Chisti, [Photo, Chandra, 1999].

9.6.2 Nawabi Period

Asafi Imambarra

It is locally known as *Bara Imambarra*. First of these Nawabs Asaf-ud-Daulla (1775-95) was responsible for raising Lucknow by means of large building enterprises. Of the several examples, most representative is that known as the great Imambarra with its mosque, courts and gateways. A well was dug in the Bawly mosque.

The water level was too low. It was constructed in 7 levels; 3 over the water and four under the water. It is connected with the river Gomti.

There is a story about immambarra [Nawab Jafar Mir Abdulla, 2000]. Asaf-ud-daulla had a desire to make the best possible things. For making immambarra different renowned architects were called. Kiffayat-ullah who was the main architect behind Taj- Mahal was also involved. He came with a very big building with tremendous symmetry. His plan was approved. But it was not possible to find out an appropriate place which will fit to the size of the Immambarra. There was a land but there stood a hut where an old lady Lado-Saquum lived. It was decided that if this hut can be included in the land, it will be possible to make the immambarra. Nawab Asaf-ud-daulla was very kind if he so desired he could take the land by force. Instead he has ordered his assistants to ask for the hut and in exchange lady Lado-Saquum can get what she desires. The lady answered that she prays and keeps *Tazia* of his prophet Mohammed. Thus she can not leave this place. Hearing this Asaf-ud-daulla himself went and begged for the place. He has promised that (i) the *Tazia* will be placed in the same place as now, (ii) it will be taken out on the same date to *karbala*. She has agreed and given her place. When asked for the reward she answered that she will donate it. It shows the generosity of the people. The Nawab has also kept his promise. There is only one wooden door where her *Tazia* is kept, and even today first her *Tazia* is taken out and then the whole *Zari*. When this was accomplished, the Nawab became very happy and has asked Kiffayat-Ullah "what you want" He has said he will be very happy to get "*Do Gaz*" land in the *Immambarra*, so that the people can also pray for him. Nawab has accepted, and even today the people pray first for Kiffayat-Ullah.

It is a 3 storeyed monument with one roof (Figure 9.7). But from outside it appears to be only one story. The walls are 12 foot thick and there are 3 foot wide roads. These are very well ventilated so that these are warm in winter and cool in summer. There is good arrangement of light also through the *Roshandan*. This is an immense and imposing conception, notable for

its grandiose proportions. This vast venture is approached by two gateways, one on each side of a thorough fare, that on the south for entrance, the other being introduced solely for symmetry. Within this southern gateway is a forecourt leading upto the other triple doorway. Through which is the main courtyard with Imambarra, a building for the observance of Muslim ceremony of Muharram. The interior is a vaulted hall of great size measuring for example 160 feet by 53 feet and 50 feet high is one of the largest apartments of its kind.



Figure 9.7 : Bara Imambarra (cir. 1784).

On the second floor there is a place from where it possible to see the main street but the people from the street can not see this opening. The roof is very heavy and its load is distributed over the air cushions. It is said that if a vacuum could be created here it will collapse because the air cushions are holding the load. It is very precisely made. There are three halls which are built on different concepts. Central hall is Persian hall which is of the shape of tray. On the left is the chinese hall. It has octagonal foundation, which later became hexagonal and had a rhombohedral dome. Around the dome there are foliated fluttings where the ladies can sit to listen to the *Majlis*. On the right hand the hall is India and its dome is of the shape of water mellon.

The main hall of the Imambarra with a vaulted roof is one of the largest halls of its kind in the world, without pillar or support measuring 49.7 meter in length and 16.16 meter in breadth and 14.95 meter in height. There is no reinforcement. The beauty of the construction is such that inspite of the sound downstairs, if two people will stand on each end (a distance of 160 feet) and will tear of paper, they will hear the sound.

Above the hall, there is a unique labyrinth of intricate balconies and passages with 489 identical doorways which gives the visitors the feeling of being lost on the way. As such it is also named *Bhulbhulayan*. There was an under ground tunnel to Faizabad which has been closed due to the accidents. Otherwise it was possible to ride on horses through the tunnel. It is said that there were 33 different type of ingredients used in the mortars and concretes used such as *daal*, *sheera*, *chuna*, *surkhi*, *gum*, *oils*, extract from different trees etc.

It is also said that the French architect Maj. Gen. Martin was surprised to see the construction of such a big roof with out reinforcement. He said to Kiffayat-Ullah that the roof will not take the load and will collapse when opened by taking away the wooden planks from under *Pad*. Kiffaya-Ullah laughed. He has put his bed under it and has ordered to open the roof one week before time. Nothing happened. That was the confidence of the artisans in the ancient period which was built on nothing but the practical experience.

The main hall of the Imambara contains the graves of the Nawab of Awadh Asaf-ud-daula, his wife Shamsunnisa and the architect Khifayat-ulla. The Asafi mosque is located on western side of the main Imambara, a *Shahi Baoli* (stepped well) on eastern side, the *Nakkar Khana* or *Naubat Khana* (Drum house) on the northern side and the famous gateway called *Rumi Darwaza* on western side. The mosque is of very pleasing architectural appearance. Steppedwells are very well described earlier (Chapter 8). This stands at an angle with the remainder of the scheme. This is placed in a symmetrical position in order to conform with the necessary orientation of such a building. A closure approach reveals an excess of ornamentation. Perforated arcade above the parapet is very spacious.

Rumi Darwaza

The Rumi Darwaza, the main gateway of the Bara Imambara complex is standing horizontally on the old Hardoe Road. It is made of *lakhori* bricks with lime plaster and plaster moldings. In this structure those concerned appear to have aimed at something large and spectacular (Figure 9.8). It is a magnificent and unparallel creation of Hindu-Muslim architecture. While viewed from the west, it looks like a large *mehrab*, formed by two extra areas, which intersects at a point on the apex, a typical Muslim style). All along the Cursive engravings lotus petals and other intricate patterns with a series of *Guldastas*, as is mentioned earlier, were provided to adorn the lofty gateway and within this three medium sized arched gateways appear in a semi circle fashion. From the eastern side, it appears like a half crescent shaped building, influenced by the Rajput style (Hindu style), having three

medium sized gateways adorned with multifoiled arches and floral designs, flanked by two minarets on both the sides. On the roof of the gateway, there is another pentagonal structure with five doorways on each wall, the roof of this geometric structure culminates in a small platform, resembling the top of Mexican hat.

Above this, a red sandstone octagonal *Chhatra* (umbrella) visible from all the sides, serves as the *Mukuta* or crown of the structure. The Rumi Darwaza is flanked by two five storeyed structures on either sides, along with two six storeyed octagonal bastions on their extreme ends.



Figure 9.8 : Rumi Darwaza, Lucknow (cir.1784).

Hussainabad Imambara

It is locally known as *Chhota Imambara* (Figure 9.9). It is located in Hussainabad. It was built by the King Mohammed Ali Shah (1837-1842 A.D). It is a complex within an enclosure wall, which consists of main Imambara building, *hammam*, and mosque. On the outer complex just to the main entrance stands *Nakkar Khana* or Naubat Khana along with two gateways on either side. The vaulted roof is capped by gilded dome in the center and a cupola each on either side. The inner hall of the Imambara contains the grave of Nawab Mohammad Ali Shah and his mother. The central part of the compound is flanked by a small tomb of Nawab's daughter Zeenat Asiya with its prototype on the other side. The *Shah-n-sheen* (raised platform) of the Imambara is decorated with *Zari*, *Alam*, *Tazia*, *Panja Patka* and some other rituals, while the hall is decorated with costly mirrors, chandeliers, paintings, photographs etc.



Figure 9.9 : Chota Imambara, Lucknow, (1837-42).

Jama Masjid

It is located at *Mohalla Thakur Ganj*. The construction of the famous Jama Masjid began by the king Mohammad Al Shah in 1839 A.D., and was completed by his two wives after his death. It was built with *lakhauri bricks*, lime plaster and decorated with colored stucco. Standing on a square lofty terrace, it has a rectangular prayer hall on the west with a magnificent facade of eleven arches, the central one being higher provided on unusually high doorway which rises above the flat roof in shapely pointed arch in colored stucco, especially the double arches, decorated with stylised flower buds. The *mehrab* facing the west bears calligraphic inscription of *Quranic verses*. The prayer hall is surmounted by three pear shaped high double domes decorated with an inverted lotus on the top and is also flanked by two octagonal four storeyed tapering minarets on either side, crowned by *chhatris* on the top.

In the last years of the previous century there had been gradually rising in Lucknow a large building known as the country seat of maj. gen. Claude Martin (1735), a French soldier, in the service of the Nawabs of Awadh. Designed by Martin himself, in what may be termed a debased Palladian style this was one of the first largest buildings of a European order to be presented and the fresh field that it opened up, the citizens proceeded to incorporate its more prominent features in the palaces and other secular structures ordered by the Nawabs and later even to make copies of pseudo-classical compositions for the same purposes. Thus there developed in

Lucknow a style of architecture of pronounced hybrid character in which triangular pediments, Corinthian capitals and Roman round arches were combined with fluted domes, ogee arcades and Arabesque foliage's, a mixture of western and eastern forms. These buildings may be the most suitably described as consisting of a debased Mughal framework, garnished with classical motifs often of appropriate type, very much as in the 16th century in England the Gothic struggled on, tricked out with elements of an almost similar character. The examples that illustrate this manifestation of the building art in Lucknow are chiefly those of a secular order. For instance the larger and smaller Chatter Manzils, two palaces erected by the Nawab Nazir-ud-din Haider (1827-37), together with the gateway to the Sikander Bagh, Chaulakha Darwaza at Kaiserbagh (Figure 9.10). Both of them were produced during the rule of Wazid Ali Shah (1846-56). Of the buildings in the Italian style in which oriental influences are negligible, presumably inspired by accidental models are the Roshan Wali Kothi, now used as deputy commissioners court and the Begum Kothi at Hazarat Ganj; on the other hand the Jama Masjid begun by the Nawab Mohammed Ali Shah (1837-42) maintains some of the characteristics of the Mughal style. In 1856 the last Nawab of Awadh was deposed which marked the real end of the Mughal style, as no building in the mode of the Mughal style was erected in Lucknow after this date.



Figure 9.10 : Chaulakha Darwaza, Kaiserbagh gate. [Photo, Chandra, 2000].

Chaulakha Darwaza, Kaiserbagh Gate

In Lucknow, the architecture developed was of a pronounced hybrid character in which triangular pediments, Corinthian capitals, and Roman round arches were combined with fluted domes, arcades, and arabesque foliage. These buildings may be most suitably described as consisting of a debased Mughal framework garnished with classical motifs. One of the example which illustrate this manifestation is *Chaulakha Darwaza* of the Kaiser-Bagh. It is a saying that since its construction cost was four lakh Indian Rupees, so is the name *Chaulakha Darwaza* (Four lakh Rupees door).

These are actually duo gateways both at the eastern and western side of Baradari at Kaiserbagh. These were built by the Nawab Wajid Ali Shah of Awadh between 1848 and 1856 (Figure 7.9). The plan of the gateways was almost identical and has polygonal design. It was focussed upon a control, rectangular passageway, which was buttressed by two large semi-circular platforms, and on the flanks of which lay, at first pairs of small, nearly square rooms, and then, pair of rectangular chambers of same length. Its western front had two projections; one rectangular; the other, a half octagonal, which formed the “*burgee*”. On the eastern front, the control passageway was also flanked by a pair of small side gates and by a pair of rectangular “*burgess*” which contained spiral-staircases, a way to the upper level.



Figure 9.11 : Close up photograph of Chaulakha Darwaza, showing wooden beams down the arch, [photo, Chandra 2000].



Figure 9.12 : A damaged part of the Chaulakha Darwaza. Here the wooden beams are distinctly visible, [Photo, Chandra 2000].

The gateways also had elevations of almost the same kind. Both had a large central round headed arch with a superimposed decorative fishes. On the fronts of both the gateways facing the inner court, their central arches had not only two flanking, small round headed ones, but their rectangular corner burgesses also had turrets with arched openings. Both had the same parapet fringes of little arches with cupolas. Above all, both were covered by semi circular, balustrade stairways, which intersected on their diagonals. These staircases have inaccurately been called “flying buttresses” or far from offering structural support, their lateral thrust had in fact to be counteracted by piers of enormous thickness.

These are made of red bricks. Stucco used to join the bricks constitutes of lime, sand and organics as is described in the Chapter 6, plaster (Part II). The gate, *Darwaza*, is in damaged condition, thus different parts are exposed. Wood has been used in the ancient period as reinforcing material. The big wooden beams are seen in the Figure 9.11 and Figure 9.12. The wood is still in very good quality and is not damaged by humidity, temperature or termites. This must have been pretreated, most probably by linseed oil. These are covered with brickwork and finally the walls are plastered with lime plaster mixed with organic additives.



Figure 9.13 : Reed reinforced wall at Tranhouse gatan 51, Visby, Gotland, Sweden [Photo, K. Balksten, 2001].



Figure 9.14 : Wooden strips reinforced wall at Tranhouse gatan 51, Visby, Gotland, [Photo, K. Balksten, 2001].

Wood was not only used as the reinforcement material in India. It was also used elsewhere. One of the example is a house at Tranhusgatan 51, Visby, Gotland, Sweden. This house is located at the sea side and is thus exposed to the humid climate. Although it is exposed to the marine

environment but surprisingly enough the water from the sea (Nordsjön) is not salty. The house was built in 1829. I got the opportunity to look at the house, which was under restoration. It is not very often when the construction details are visible. The reinforcement is shown photographically in the Figures 9.13 and 9.14. Figure 9.13 shows the reinforcement done by the reeds and in the Figure 9.14, it is seen that the reinforcement is done by wooden strips. The plaster deteriorated and crumbled but the wooden reinforcement is still in good condition. The reinforcement is covered with lime plaster.

9.6.3 British Period

Amongst the colonial buildings of Lucknow worth mentioning are; Residency complex, Victoria memorial, clock tower, Lamartenier etc. Here, Residency complex is elucidated.

Residency Complex

The Residency complex was set up at the right bank of the river Gomti in 1775 by the Nawab Asaf-ud-daula (1775-95 A.D) for the British Residency, after shifting the capital from Faizabad to Lucknow. The main Residency building of three storeyed having a *tykhana* (underground chamber) under its annexure, was constructed during the reign of Nawab Saadat Ali Khan (1798-1814 A.D) which was used from by the Resident and chief Commissioner of Awadh till 1857. The main entrance of the Residency was from the eastern side, under a large double columned portico. To the western side there was a wide, lofty colonnaded veranda, and the whole area of Residency Complex covers thirty three acres of land, comprises several buildings and gardens, entered through an arched gateway known as Baillie Guard gate. Beside the main Residency building, there were banqueting Hall, Treasury Building, Dr. Fawyers house; Begum Kothi mosque, Imambara, Church and Cemetery giving an indication of varied nature of activities within the complex.

The roofless buildings of Residency Complex had suffered great damages during the historic seize of 1857 which are still servicing in ruinous condition (Figure 9.15).



Figure 9.15 : Residency Complex.

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1. BINDERS

Buildings are constructed from mud, stones, bricks and concrete. For joining the stones and bricks some mortars are used, and at times the walls are plastered. The durability of a building depends upon the materials and the method used for making it. These are very closely associated to each other and is not easy to say which one is more important. Discrepancy in any of these factors will hamper the quality of the building.

Plasters, mortars and concrete constitute chiefly of binder, aggregates, and water. Binders are the materials which cement the aggregates together. The quality of plaster, mortar and concrete is controlled by the type and quality of the binder, aggregates, and the method used to produce it. Different types of binders are used for making plasters, mortars and concrete; clay, lime, gypsum and cements. Some additional binders are also used which have pozzolanic properties. Modern concrete is made with Portland cement as binder and the industrial by-products like, fly-ash, condensed silica fume, and blast furnace slag as the pozzolanic material. In the ancient period, the binders used were mainly, clay, lime, and gypsum. Portland cement was developed much later in Europe. Pozzolanic materials used were pulverized burnt bricks and ashes from the agro-waste. In this chapter attention is given to the clay, lime, gypsum, and pozzolanic materials whereas cements are only touched.

1.1 Clay

Clay is one of the most widespread and earliest mineral substance utilized by man in building construction. It carries the records of the ancient races inscribed upon tablets, in brick buildings, in monuments, and in pottery. Its products portray the history of man. The term clay is applied to earthy substances consisting chiefly of hydrous aluminum silicates with colloidal material and specks of rock fragments, which generally become plastic when wet and stone like under fire. These properties give clays their usefulness, since they can be molded into almost any form, which they retain after firing. Clays are used in ceramics, earthen wares, in building and in making bricks. The artists believe in the tenet:

“Respect the Soil and it will reward you richly with your creation”

1.1.1 Definition of Clay

Clay is very often confused with soil, mud and earth. As for example; mud houses, clay bricks, soil cements etc. Some definitions are given here which will make distinction between this nomenclature.

There are many definitions of clay. In most of these definitions the fineness of the particles is stressed. One of the earliest to associate a definite particle size range with clays was Kirwan [1794] who comments that;

“Clays are for the most part diffusible in water, and do not immediately sink in it as sand do; or if so compact as immediately sink, they soften, crumble or molder away in it, some sooner some later, either to a ductile sticky pulp, or to a powder. They harden when heated, scarce ever effervesce with acids and are soluble in them with difficulty. The constituent parts of clays are argo (alumina) and silicious stones from the size of $1/100$ ca 0.25 mm to $1/10000000$ (ca 0.025 μ) of an inch. All other ingredients constant (except water and there are many extraneous soil composition.”

One may compare this with the comments of Merrill [1906];

“The only fracture characteristic of all clays is that of plasticity, when wet, and this is dependent, apparently upon the size and shape of the individual particles, and in some cases at least upon the presence of colloidal matter.”

Without going into specific details a demarcation between clay, soil, and earth can be made as follows;

Clay - The smallest fraction in the particulate breakdown of a soil (less than 0.002 mm diameter). It acts as the binder in earth based building materials.

Clay - sub soil - Soil contains clay and other materials. Clay is a part of the soil, amount of which varies from place to place. As such soil also contains bigger particles than the clay. It is a raw material for most types of earthen buildings.

Mud - It is a workable mixture of clay soil and water. It may also contain fine aggregates like sand or stone dust.

Earth - It is a general term for ground. It may or may not be good for use in the building construction. It includes all type of inorganic and organic material. It is one of the five basic elements of nature; *Earth, Sky, Water, Fire and Air*. Therefore, it should not be confused with the clay and soil.

1.1.2 Composition and Properties of Clays

Clay is not a mineral but an aggregate of minerals and colloidal substances. The constituents are so fine that, until the use of the X-ray diffraction analyses for mineral determination, its exact composition was unknown. Some clay minerals can be observed in detail only by electron microscope at magnifications greater than 5000 times. Residual clay is often called kaolin. It was formerly thought that kaolin was composed of the mineral kaolinite. But now it is known that, although kaolin contains considerable kaolinite, other clay minerals are also constituents.

Clay Minerals

The clay minerals are flakelike, lathlike, fiberlike, or hollow tube-shaped, and they are identified by the microscope, x-ray diffraction analyses and differential thermal analyses. They have replaceable bases; the one formed is determined by the mode of origin and may change in response to changes in environment. The clay minerals are:

Group	Composition
A. Kaolinite	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$
B. Montmorillonite	$\text{Mg}_2\text{Al}_{10}\text{Si}_{24}\text{O}_{26}(\text{OH})_{12}[\text{Na}, \text{Ca}]$
C. Hydrous Mica	$(\text{OH})_4\text{K}_2(\text{Si}_6\text{Al}_2)\text{Al}_4\text{O}_{20}$
D. Miscellaneous	
1. Palangorite	$\text{Mg}_5\text{SiO}_8(\text{OH})_2 \cdot 4\text{H}_2\text{O}$
2. Sepoilite	$\text{Mg}_6\text{SiO}_8(\text{OH})_2 \cdot n\text{H}_2\text{O}$
3. Allophane	$\text{Al} + \text{SiO}_2 + \text{H}_2\text{O}$

The chemical formulas are not indicative of the structural composition of clay minerals. Kaolinite has, for example, a composition expressed as $(\text{OH})_8\text{Si}_4\text{Al}_4\text{O}_{18}$, which indicates that kaolinite consists of an Si_4O_{10} sheet structure (Figure 1.1) with Al^{+3} substituting for some Si^{+4} , and with (OH) molecules oriented within and above the pockets formed by four tetrahedrons in an octahedral structure. As silicon and aluminium have different ionic charges of +4 and +3 respectively, the ionic charges of the colloidal particles are different; this enables them to absorb water to balance their charges and provide the plasticity to clays.

Clays also contain other substances such as rock fragments, hydrous oxides, and colloidal materials. Properties of clay are greatly affected by the presence of impurities. Quartz; decreases plasticity and shrinkage and

helps make the clay resistant to high temperature. Silica in colloidal form increases the plasticity. Alumina makes clay high temperature resistant. Iron oxide as well as feldspar, lowers the temperature of fusion and acts as a flux; it is also a strong coloring agent- a little of it gives a buff- colored clay, much of it, more than 5% makes a red product, white burning clays should have 1% or less.

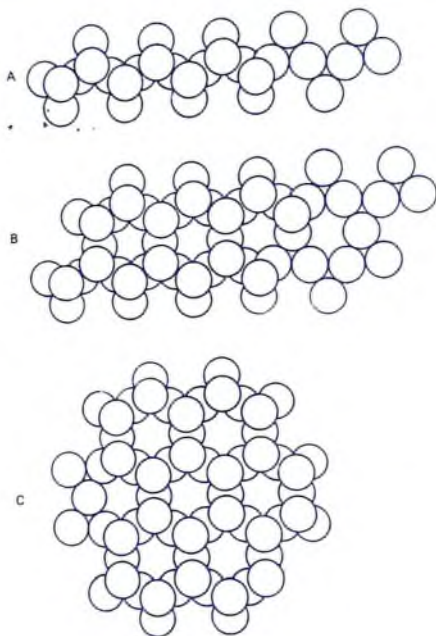
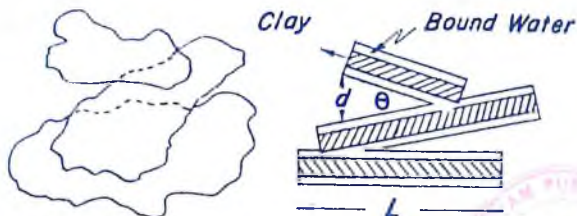
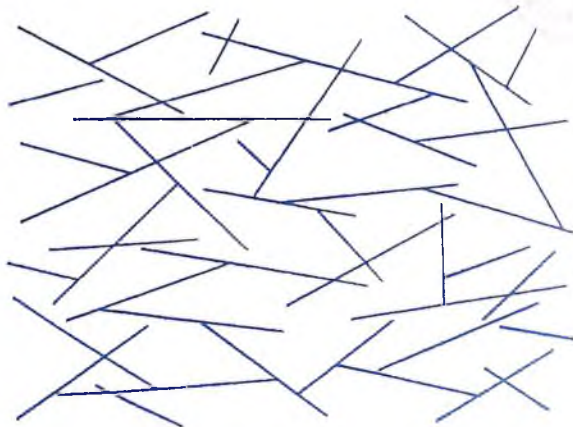


Figure 1.1 : Structure of clays; Single chains (A), double chains (B), and sheets (C), each illustrating a sharing of oxygen ion by adjacent tetrahedra. In (A) each tetrahedra shares two oxygens; in (B), some share two and some share three, and in (C) each shares three oxygens. Single chains are joined to other single chains and double chains are joined to other double chains by positively charged ions (such as iron, magnesium, sodium, calcium, and potassium). Similarly, sheets are joined to other sheets by such ions, making stacks of sheets. (From Ojakanges and Darby, 1976, *The Earth*, McGraw-Hill Book Company, New York).



PARTICLE ASSOCIATION



GEL STRUCTURE

Figure 1.2 : Schematic drawings of interparticle associations in the range of mud concentration, Mungan, N. and Jessen, F.W.[1963], *Studies in fractionated Montmorillonite suspension, Clay and Clay Minerals, Monograph 13, Earth Science series, ed. Earl Ingersson, Pergamon Press 1963. p 293.*

Plasticity

Plasticity is an essential property of clay which governs its use. There are many methods for measuring the plasticity. Most common is the measurement of shrinkage after air drying of the clay sample. The higher the plasticity of clay, the higher will be its shrinkage. Clays are subdivided basing upon its plasticity. High plasticity clays have water requirement of more than 28% and air shrinkage 10-15%; clays of medium plasticity with water requirement from 20-28% and air shrinkage from 7-10%; and clays of poor plasticity with water requirement less than 20% and air shrinkage from 5 to 7%.

Type of Clays

Clays are of different types; kaolines or China clays, ball clay, fire clay, illite, bentonite, fullers earth, and laterite clay. Clays are used in ceramics, refractories and as building materials. Laterite clay soils have been a major building material for the rural population in many countries. The factors that make these soils so popular is their availability and cheapness. But these soils are not very durable as building materials mainly due to lack of requisite strength. Besides this, in very wet climates, they absorb a huge amount of water which reduces their strength, and results in cracking when drying.

The builders were acquainted with these problems and have used some additional materials to improve these properties. They have stabilized the soil by using natural organic materials, lime and sand.

1.1.3 Clay Stabilization

Bonding of the Clay Particles

Stabilization of soil is complicated. Before coming to the stabilization of soil it is desirable to understand how the clay particles are bonded together.

Hinge theory [Mungan and Jessen 1963]; It is proposed that clay particles under the influence of all active force will assume random positions in a gel, but nevertheless, will maintain a bond with each other, thus forming a continuous solid phase. The nature of the bond is best explained through showing of bound water or water of hydration between two particles.

Clay particle may absorb 1, 2 or 3 water layers on each silica surface. Each water molecule has two protons that it can share. When 2 clay particles are in proximity along some point or line edges, the protons of the water from one particle will be shared by the other. Thus forming a bond. The association can be between, edge and surface or two edges. This gives rise to the name "Hinge".

A net work of interlacing and randomly hinged particles form the gel structure (Figure 1.2). The strength of such a gel will be influenced mostly by the length of the hinge bond (L), by the distance (d) between two ends of particles and by the electrostatic attraction forces. For a slope gel structure, it is visualized that most of the particles will hinge along line contacts. To accomplish this, despite the highly irregular outlines, the angle $\bar{\epsilon}$ will have to be very small, $2\text{--}10^\circ$.

The distance between particle ends is a function of L and $\bar{\epsilon}$. For specific clay concentration L becomes smaller as the particle size decreases. With far greater numbers of particles, the angle should also decrease, consequently, increased gel strength should be expected.

The thixotropic properties and the strength of the gel can be explained, using this hinge theory:

1. When a gel sets, all particles have formed bonds with each other, in a random fashion, along points, or lines, sharing their bound water. The result is an interlacing network of solid particles forming a continuous network. In this network, there will be chambers occupied by liquid water. These chambers are not interconnected. As a result, the gel behaves like a solid. Under agitation, particle bonds are broken and some of the bound water is disrupted from the surfaces. The liquid water volume is increased and water becomes the continuous phase, with the clay particles isolated from each other. If the agitation is topped, some liquid water will orient on particle surfaces (become bound water), particles will form hinge bonds, and the gel will be restored.
2. Differences of gel strength between Ca^+ and Na^+ clays follow from this theory. Na^+ clay will develop higher gel strength because it attains smaller particle size, resulting in a greater number of particles in the gel and smaller (d) distances and ($\bar{\epsilon}$) between the particles. Furthermore, Na^+ clays hydrate to greater extent, resulting in a greater amount of bound water, and therefore, a larger volume fraction of the solid in suspension. Finally, Ca^+ clay particles tend to aggregate forming clusters or sandwiches, thereby decreasing the effective surface upon which water can bind itself.
3. If the clay concentration is decreased, there will be more liquid water available for each particle. Water will enter between particles, keeping them apart by greater (d) distances and larger angles $\bar{\epsilon}$. However to reach this state the clay concentration should be low.

The hinge structure proposed will apply equally whether the particles are considered to be flat plates, disks, or fibers, since the hinge bond can be around a mere point.

Soils can be stabilized in different ways. Two of the methods which are generally come a cross are by: i) mechanical treatment, ii) chemical treatment or chemical treatment aided by mechanical treatment. During mechanical treatment there will be compaction of the soil particles whereas during chemical treatment there will be both physical and chemical interactions.

Mechanical Treatment

The most widely used method of stabilizing the soils are by mechanical treatment- mixing by feet as was done in the ancient period or by pugging as is used in the ceramic industry. In this way the charge on the particles of the clay will be lessened, and they will be compressed. The distance between the particles d (Figure 1.2) will decrease, the angle " ϵ " will also diminish. More water will thus be released which was entrapped. During mechanical treatment bigger clay particles may also break down to finer ones. These will provide better workability, plasticity and will produce well compacted soil which will be dense, less permeable. Consequently will produce mass of stronger mechanical strength and better durable properties.

Chemical Treatment

Chemical treatment of soils is done by mixing inorganic and organic compounds. Inorganic material used for soil stabilization is lime and the organic materials used are the natural organic materials "agro-materials" found in nature or the synthetic chemicals produced in the factories. Stabilization of soils with lime is described in the Chapter 1.2.

The chemical treatment of soils is aided by the mechanical treatment. This is actually what was done by the ancient builders and this practice is still used in the villages to-day for making mud houses when leaves from the trees and other natural organics are added with soil and water, mixed by feet and left for some time to mature. The process is repeated several times till it has attained the requisite plasticity and workability. There is no standard or any hard and fast rule. The maturity time is judged by the able mason.

Maturity time is needed so that the natural organics will have time to disintegrate; like in the case of leaves. They rot and a type of pulp is made, which is not easy to mix without mechanical treatment. Besides mechanical treatment while ensuring homogeneous mixing of the organics, also helps in compaction of the soil as is mentioned in the mechanical treatment section.

Interaction of Proteins with Clay

Many natural organic materials have been used for clay stabilization. Most of them contain proteins which interact with clay and produce complexes, which enhances the durability properties. The interaction takes place through ion exchange.

For example the stabilization of soils by ion exchange alone with large cations, such as amines obtained from fatty acids.

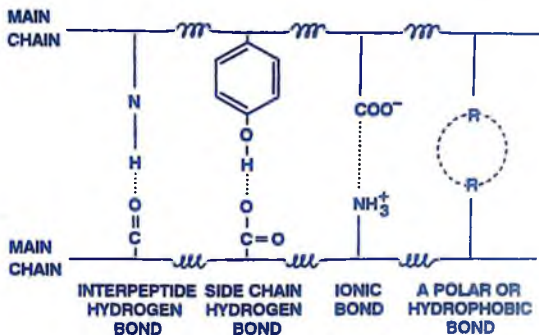


Figure 1.3 : Schematic diagram illustrating the types of covalent bonds; (From Chandra, S. and Aavik, J. *Int. Cem. Comp. Lightweight Concr.* 9 [2], 91, 1987, with permission).

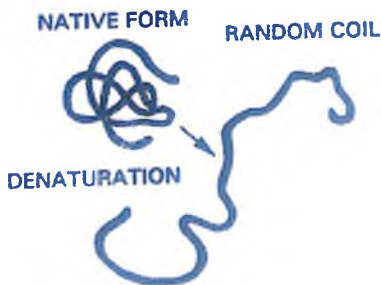


Figure 1.4 : Denaturation of Protein, (From Chandra, S. and Aavik, J., *J. Int. Cem. Comp. Lightweight Concr.* 9 [2], 91, 1987, with permission).

The tissues of animals and plants contain most of their nitrogen in a basic form or in a form which becomes basic upon hydrolyses. Organic matter derived from these sources will be capable, therefore, of reacting like basic compounds. This should make possible a combination between the basic or positive spots of the organic matter and the acidic or negative spots on the crystal lattice of the clay. In fact, individual particles of clay organic matter will have a greater number of positive spots resulting from free amino groups. Likewise, individual clay crystals, having a cation exchange capacity will have a great number of negative spots. If the two particles should orient themselves in such a manner that there was a mutual attraction between many of these spots, a stable combination would be obtained. In this way the clay crystals must be covered by a "net work" of organic material.

Denaturation and interaction of proteins is well described by Chandra [1994]. Proteins are built up by amino acid residues arranged in long chains and joined by so-called peptide bond $=\text{CONH}_2=$. In nature, the sequence of amino acid residues along the chain is unique. Some typical features of the side chains are built up by segments. Each of these segments can have a polar and non polar character, depending on which amino acid predominates. Polar segments make the chain hydrophilic while nonpolar segments make it hydrophobic. Thus a single protein molecule may have several hydrophobic and hydrophilic segments along the chain (Figure 1.3), ionic bonds prevail in the hydrophilic region while nonpolar bonds are predominant in the hydrophobic regions. This activates the surface of proteins. This surface activity is supposed to be the major cause of the air entraining character of proteins. In their native state, soluble proteins have a unique globular form in which the chains are folded in a manner determined by the amino acid sequences. Parts of the surface of the molecules are hydrophilic with higher concentrations of glutamic and aspartic acids, lysine, and arginine. Other parts are predominantly hydrophobic, with mainly aliphatic amino acids. When proteins are mixed in a material having pH value more than 12, separation and unfolding of the chains take place. It is a type of alteration of molecules known as denaturation and orientation (Figure 1.4) [Chandra and Aavik, 1987]. Thus more hydrophilic and hydrophobic phases are exposed. The hydrophobic part goes to the air phase (pores and capillaries), and the hydrophilic part goes to the water phase. At high pH values, hydrolysis of the chain takes place, splitting it into parts of lower molecular weight. Proteins form salts with alkalis and complexes through cross-linking with metal ions.

Above the isoelectric point, proteins (nucleoside and amino acids) behave as acid anions (and possess negative charge) while they behave like bases below the isoelectric point. The compounds are slightly adsorbed onto the soil or clay minerals above the isoelectric point. Minerals like the montmorillonite group, with accessible internal surfaces, form interlamellar complexes. Adsorption occurs over the external clay surface also. The first layer on the surface is always much more strongly adsorbed than the other layers. The macromolecule that are adsorbed in cationic form displace metal cations from the clay. A small proportion of the macromolecule are adsorbed by the other mechanisms, possibly by hydrogen bonding. X-ray diffraction studies of the adsorption of albumen, gelatin, hemoglobin, casein, protamine, pepsin, and pancreatin on montmorillonite established that these proteins were adsorbed between the silicate sheets [Ensminger and Geisseking 1939 and 1941].

Proteins are adsorbed in the form of cations. In their study on nucleoprotein, Goring and Bartholomew [1952] also reported cationic interaction. Further, it is reported that the adsorption was greater when the metal ions present were divalent. Similar results were reported by Kragh and Langston [1962]. These results are sufficient evidence to say that the clay protein complexes are formed by adsorption involving cationic exchange. Further, the most stable structures are those in which a mono-molecular layer of macro-molecules is adsorbed. When this adsorption is on the internal surface of the mineral, it is protected from the chemical attack.

Resistance to Biological Matter

Clay adsorbed organic materials may be resistant to biological decomposition. Waksman [1936] makes the following statement;

“Clay colloid forms compounds with humus colloid, thus preventing its rapid decomposition.”

Mattson [1932] has reported that the adsorbed proteins are more resistant than free proteins to microbial decomposition. It is found that a complex containing 100 parts of silicic acid and 92 parts of gelatin did not putrefy in a moist state [Graham, 1861].

Sideri [1936] suggested selective orientation as the reason for the reaction between clay and humus. Meyers [1937] reported a reduction in exchange capacity of clays when mixed with organic colloids and explained it on the basis of polar adsorption. According to Meyers this polar adsorption should result in a close packing of organic colloidal particles on the surface of clay. Such packing would result in a reduction in the exchange capacity not because

of a chemical reaction but because of stearic hinderance to the passage of ions from the ends and sides of the organic colloids. He expressed the belief that absorption would probably be a factor in reducing the exchange capacity of inorganic colloids by covering the exchangeable ions on the surface of the clay and thus permitting only the ions within the expansible lattice to be exchangeable.

Trace Chemicals

Many chemical stabilizers have been used, but there are trace chemicals, which can improve stabilization by any of the four mechanisms; (1) aid mixing, (2) aid compaction, (3) strengthen soil- additive bond and (4) cause reaction in addition to the main stabilizer reaction.

Higher Density

Considerable experience has proved that other things being equal, an increase in the density of a stabilized soil generally results in an improvement in strength characteristics. Dispersing agents permit a higher compacted density of fine grained soils by soil surface-chemical reactions. A chemical, which permits the particles of a treated soil to pack more tightly could strengthen the stabilized soil. The dispersing agents decrease agglomeration and increase cohesion. Thus they can alter wet soils and can make them easy to handle. A soil, for example, that in its natural state was too wet to be compacted could be "dried" with an dispersing agent treatment and then compacted. Chemically aggregated soils compact to a lower density and possess a much higher permeability than the untreated soils. By increasing cohesion and reducing water pick up, aggregates strengthen soils exposed to moisture. It is reported that a 0.1 % treatment of an aggregate raised the bearing ratio of soaked silt from 1 to 10. The samples were not dried after treatment [Lambe, 1955].

Influence of Particle Size

Fine grained soil improves the properties. Incorporation of a dispersant in a soil results in an increase of compacted density, an increase in water resistance, a reduction of optimum water content, and reduction in compressibility, permeability, and frost susceptibility.

These beneficial effects of dispersants have on compacted soil come from the denser structure and more orderly arrangement of particles that are obtained when the particles are able to slide relative to each other more easily. The improvement is therefore permanent until some mechanical force disrupts the new structure.

Soil stabilization is mostly done using the natural organic found in nature; such as leaves from the trees, milk from various trees, pulp of various fruits etc. These will be discussed in the Chapter 4 "Natural Polymers". When these are added from practical aspects two types of interactions take place: 1) physical and 2) chemical. In the first case, the natural fibers help in binding like reinforcement, retains moisture; hinders fast drying of soil, and increases strength. In the second case, the carboxylic part of the organic interact chemically and produces complexes which are stable and have water repelling characteristic. This increases its durability. The shrinkage of the soil is further controlled by using the coarse aggregates like sand or broken stones. By these additions the flocculation and agglomeration of the clay is decreased. Consequently the durability properties are improved.

Soil Stabilization with Lime

Soils have been stabilized with lime since ancient period. In spite of so long period of its use as soil stabilizing material, no concrete theory has been put forward stating the mechanism involved. What is known is that lime stabilizes and produces soils of higher strength.

Soil stabilization is a two stage phenomenon. The initial stage of this reaction, which starts spontaneously after the addition of lime is generally referred to as the "immediate amelioration". The second stage which is a slower process; is chemical reaction.

Chemical Reaction

Calcium hydroxide reacts at comparatively low temperature with clays, quartz and other silicates to produce calcium silicate hydrates (CSH) of high specific surface area. These are referable to the known tobermorite-like phases. Generally it also produces well crystallized calcium aluminate hydrates. Diamond et.al. [1965] has studied the interaction of lime on certain clays. They have reported that the reaction can lead to an almost decomposition of the silicate phases under appropriate conditions.

Lime attack on quartz seems to produce CSH (gel) regardless of the experimental conditions; kaolinite and montmorillonite on the other hand may produce either CSH (gel) or CSH(I). At slightly higher temperature however, C_3AH_6 may be produced; otherwise the alumina bearing compound usually has hexagonal phase similar to C_4AH_{12} . No quaternary phases are formed. They have concluded that the mode of attack involve dissolution at the edges of the silicate particles due to the high pH maintained by the calcium hydroxide, followed by the precipitation of the reaction products. Under

appropriate conditions CSH(I) of foil shaped morphology has as high a degree of effectiveness as a cementing agent as does fibrous CSH(gel) produced under similar condition.

There are different types of calcium silicate hydrates. Though their chemical composition is the same their morphology is different. These can also be poorly crystallized in which case these are not usually distinguishable from each other by X-ray diffraction analysis. These can be identified and differentiated by thermal gravitation and thermal differential analysis (DTg and DTA). These silicates can be defined as follows depending upon the work of Taylor [1961], Brunaur and Greenberg [1962] and Diamond [1965].

CSH (gel)- Morphology fibrous, individual fibers appearing to consist of rolled-up sheets, often cemented laterally to form lathlike sheets. DTA yields weak exothermic peak at 850-900°C.

CSH(I)- "Foil like", "Snowflake", or very thin platy morphology, often crinkled or crumpled. DTA marked by strong, sharp exothermic response at 850-900°C.

CSH(II)- Morphology fibrous, some times as cigar shaped bundles. DT yields small exothermic bulge at about 400°C, and relatively small high temperature exothermic peak at 850-900°C. XRD pattern show a peak 1.56Å.

Mechanism of Chemical Interaction

The mechanisms of chemical interaction are as follows; i) cation exchange, ii) flocculation and agglomeration, iii) carbonation, iv) pH- dependent cation exchange capacity and v) physical adsorption theory.

Cation Exchange

Cation exchange usually takes place in the presence of an aqueous environment, and the ions generally have considerable solubility. However, clays may take ions from water suspensions of very insoluble substances and resistant minerals, and the reaction can take place in the presence of relatively little water. Cation exchange in a clay results from the attraction of positively charged cations to the negatively charged clay particles. The affinity with which a cation of one type replace a cation of another type depends mainly on the valency, availability of different cation types and their size. The general order of replaceability of the common cations usually found in soils is given by the lyotropic series $\text{Na} < \text{K} < \text{Ca} > \text{Mg}$ [Grim 1953]. In general cations of higher valency will tend to replace the cations of lower valency. The cation exchange reaction results in a suppression of the diffuse

double layer due to the increase in the cation valency. As a result, the soil, which originally had a dispersed soil structure will tend to become flocculated. The flocculated clay will have a reduced plastic index, decreased swelling characteristics and an improved texture.

The primary effect of adding lime to a soil water system is to provide an excess calcium cation (Ca^{++}). These will have the tendency to replace such weaker cations as (Na^+) or potassium (K^+). There are however controversies to this mechanism. It is shown that even though nearly all the clays in their natural condition were already calcium saturated, the usual changes in their physical properties occurred [Clare and Cruchley 1957]. It implies that the changes in the physical properties of clay due to the lime treatment is not due to the cation exchange. Diamond and Kinter [1965] have also reported that although the montmorillonitic soils contain in the exchange complex, these soils also exhibit all the classical deficiencies associated with montmorillonite soils.

Flocculation and Agglomeration

The addition of lime to a fine grained soil causes flocculation and agglomeration of the clay particles. As a result, there is an apparent change in texture with clay particles "clumping" together into a larger sized "aggregate".

There are a number of mechanisms to clarify the flocculation mechanisms. But there are controversies also. Schofield and Samson [1953a, 1953b] have noted that the increased negative charges on the edges of the clay particles as a result of the dissociation of hydrogen ion from the SiOH groups at the edges of crystal lattices will contribute to flocculation. This phenomenon must be associated with an increase in pH in the soil. But this appears to contradict the diffuse double layer theory because an increase in pH value will cause an increase in the effective negative charge of the particles which, in turn, will promote deflocculation. Herzog and Mitchel [1963] have explained that flocculation and agglomeration is caused by the increased electrolyte content of the pore-water and also as a result of ion exchange by the clay to the calcium form. The increase in electrolyte concentration suppresses the diffuse double layer, thereby promoting flocculation of the soil particles. It is further emphasized that the flocculation of clay occurs as a consequence of the addition of lime, but the flocculation is nearly not the mechanism by which lime stabilizes the soil.

Carbonation

Carbonation is a process, where calcium and magnesium carbonates are formed when lime reacts with the carbon dioxide from the external atmosphere or micro-organic activity in the soil. Calcium carbonate formed in situ is known to be cementitious [Deshpande, 1964], but its formation will generally be at the cost of much more effective cementing agents, which would have formed. Many researchers support the view that carbonation is probably deleterious to overall strength gains and precautionary measures are to be taken to minimize carbonation especially during the actual construction [Hilt and Davidson, 1960; Herrin and Mitchell, 1961; Thompson, 1967]. In some studies it is demonstrated that even though atmospheric carbon dioxide was precluded by sealing the samples, the characteristic modifications of properties were still observed. Thus the carbonation can not be seriously considered as the principal explanation for amelioration.

pH Dependent Cation Exchange Capacity

Hilt and Davidson [1960] stated that:

“The mechanism is either a cation exchange or a crowding of additional cation onto the clay. Both processes change the electrical charge density around the clay particles. Clay particles then become electrically attracted to one another, causing flocculation or aggregation“.

This has been seconded by many other researchers. It has been proposed that excess calcium cations derived from the lime would in some manner crowd onto the clay particles and cause them to become electrically attracted. The process would result in flocculation with weak bonds developed between them. Ho and Handy [1963] explained that the increased adsorption of calcium ions to the clay surfaces at high pH values may be the cause of better bonding between the particles. Diamond and Kliner [1965] have criticized this mechanism. They pointed out that it would be unlikely for unlimited crowding of positively charged cations to occur on the limited clay surface because of the limited number of SiOH- groups on the edges of the clay particles that could dissociate to generate enough negative charges to accommodate all the excess exchangeable calcium cations.

Physical Adsorption Theory

Diamond and Kliner [1965] proposed that amelioration involves the physical adsorption of calcium hydroxide molecules onto the clay surfaces. They suggested that the proposed adsorption process removes calcium ions and

hydroxyl ions from solution in stoichiometric proportion and causes an almost immediate but limited chemical reaction to occur between the alumina bearing edges of the clay particles and the lime adsorbed on the clay surfaces. As a result of this chemical reaction, small amounts of the cementing compound tetra calcium aluminate hydrate are formed at the points of contact between the edges of one particle and the faces of adjacent particles in the card-house structure of the flocks. The formation of these small quantities of cementing products at the points of contact is considered to be responsible for reducing the plasticity, shrinkage and swelling of lime -modified soils. Following this immediate reaction, a supplementary and somewhat slower reaction of the silica with lime at the same reaction site occurs forming calcium silicate hydrate.

Influence of Soil Type

Soils vary very much in their mineralogical composition and in their physical properties. All the soils do not react with lime to form cementing agents. Even if they react the degree of reaction varies. Generally highly plastic soils are more reactive with lime than the soils with low plasticity. Clays rich in montmorillonite react readily with lime, while clays containing mainly illite, chlorite, vermiculite or kaolinite mineral are less reactive. Silty soils may or may not react with lime depending on their mineral composition, and sandy soils are usually too coarse to react with lime [Anderson and Shields, [1963].

Influence of Lime Content

Lime affects the soil in two ways; i) lime modification and ii) lime stabilization. In the first case the major stabilization objectives are plasticity reduction, improved workability, and reduced swelling potential. Lime stabilization on the other hand is concerned primarily with strength improvement produced by the pozzolanic reaction with the soil and lime. Lime -modification requires a lower percentage of lime as compared to lime stabilization.

When lime is first added to the soil, the immediate effect is a decrease in the plasticity of the soil. It continues to decrease upto certain limiting value. When this limiting value is reached, additional increase in lime content usually do not result in any further decrease in the plasticity. This point is termed as "Lime fixation point" or the "Lime retention point". The amount of lime added for establishing the "Lime retention point" is held permanently by the soil and is not available for the pozzolanic reaction unless lime in excess of the "Lime -retention point" is added [Hilt and Davidson, 1960;

Ho and Handy, 1963]. The subsequent addition of lime causes the development of strength. However this statement is conflicting.

Concluding Remarks

Clay consists of fine particles and is the sole binding component in the soil. Properties of clay depend upon their chemical and mineralogical composition. These properties allow to put them in different types like, kaolinite clays, ball clays, montmorillonite clays etc. But the actual behavior of a particular clay depends upon its crystal structure i.e how the individual elements are placed. Soils are used in building construction. The buildings made of soils have low strength and not very durable. These properties are improved by stabilizing the soils. The stabilization is done by treating the soils mechanically, chemically or chemically aided by mechanical treatment.

In mechanical treatment, the soil and water are mixed by beating clubs or kneaded by feet, and left for some time for maturity. The process is repeated till it has attained desirable properties judged by the able man.

There is electro-static charge on the clay particles. During the mechanical treatment when the clay is beaten by clubs or kneaded by feet, this positive charge will be lessened and the particles will be compressed. The distance between the particles will decrease. More water will thus be released which was entrapped. Further, the bigger clay particles may also break down to the finer ones during this process. These will provide better workability, plasticity and will produce well compacted soil which will be dense and less permeable. Consequently this will produce mass of stronger mechanical strength and better durability properties.

Chemical stabilization is done by adding natural or synthetic chemicals or lime and then mixing them by mechanical treatment. In this way the chemicals get mixed homogeneously besides obtaining the other properties stated above during the mechanical treatment. In addition to this, the chemicals interact chemically with the clays. The interaction is through cation exchange. Proteins, which are the major component of most of the natural organic material interacts with clay making complexes. These complexes are stable in different environmental conditions. Clays also interact with humus, this increases the resistance against micro-biological attack.

Soils if treated properly with the appropriate natural organic material, mixed properly by mechanical means and matured for adequate period of time, will produce very dense material of high strength and durability properties.

1.2 Lime

Lime and lime products have been used from a very early period in the history of civilization. The earliest traces of the use of lime in constructional work are of lime plaster and stucco in India and in early Egyptian buildings [Flinders, 1909]. Some of these date around 2300 B.C are still hard and intact. Part of the work apparently was executed in a mixture of lime and burnt gypsum plaster. A lime gypsum plaster was used at times in the masonry to fill joints and level up hollows; this was used over sculptures to provide a good surface for coloring. The properties of plaster depend upon the type and quality of lime used for making it. These subsequently depend upon the type of raw materials, and burning technique used for producing lime, slaking process of lime thus produced, the method of making plaster and the application technique.

Building lime is produced by burning calcium and magnesium rocks; such as chalk, limestone, dolomite and marl bearing limestones, dolomite and marl bearing chalk. It is also produced by grinding some minerals like oyster shell, conch etc. Indian subcontinent covers a vast area varying in geography and environmental conditions. Accordingly the rocks found in different parts of India also vary. Transport facilities being not so good as today in the ancient period, the lime was produced using the locally available raw materials. For example, in Bihar and Uttar Pradesh limestone rocks are found. Lime is thus made using limestone. The location of the limestone is shown in a map in the Figure 2.1, section 2. In other places like those situated on the sea side plenty of oyster shells "*Seep*", and conch "*Sankh*" are available. Thus the lime is made from them. The type of lime varies according to the raw-materials from which it is made. Even if the same raw material is used for making lime like for example limestone its properties may vary as there are different kinds of limestone.

1.2.1 Classification of Binders

Properties of the mortar are mainly controlled by the type of binder used, which depends upon the type of raw materials used for producing it. Vicat has given the following classification of binders [1828];

- Non-hydraulic, or lime rich <10% foreign matter, > 90% lime
- Hydraulic lime; 10-30% clay and 60-40% lime
- Cements, 40-60% clay and 60-40% lime
- Pozzolanic cements, 70 to 90% clay and 30 to 10% lime.

Lime, which contains clay or the lime whose basic modulus ranges from 1.7 to 9 as calculated by the formula below is characterized as the hydraulic lime:

$$M = \frac{\% \text{CaO}}{\% (\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3)}$$

Hydraulic lime is available in two kinds; a weak hydraulic lime with a modulus of 4.5 to 9 and a strong hydraulic lime with a modulus of 1.7 to 4.5. If the burning product has a hydraulic modulus of less than 1.7, it is referred to as Pozzolanic cement ($m = 1.1$ to 1.7), and greater than 9, is referred to as air hardening lime.

1.2.2 Hydraulic and Non-Hydraulic Lime

There are two types of lime; the one having the hydraulic property is known as “hydraulic lime” and the other which does not possess the hydraulic property is known as “non hydraulic lime.” Non-hydraulic lime is produced by calcining chalk. It is calcium carbonate CaCO_3 . The lime produced is very pure whereas the hydraulic limes are produced by calcining a mixture of clay minerals and limestone. Frost [1811] and Vicat [1818] have produced hydraulic lime by calcining a mixture of clay and chalk.

The main raw material used for making hydraulic lime is limestone which contains a good proportion of clay. Other impurities such as iron and sulphur may also be present. Firing procedure is the same as for the non-hydraulic lime, but the reactions during calcination are more different. The sintered product contains calcium aluminates and silicates together with calcium oxide. The quality of lime produced very much depends upon the composition of raw material and the firing schedule. To be more precise lime can be divided in four different groups:

1. Non-hydraulic lime, high calcium limes or “fat” limes; produced from carboniferous and pure coralline limestone and white chalk.
2. Semi-hydraulic or moderately hydraulic limes; produced from grey chalk, silicious limestones, and argillaceous limestones (containing clayey matter—alumina and silica, in the form of hydrated aluminum silicate).
3. Hydrated limes; produced from lias limestone and chalk marl.
4. Magnesium limes; produced from magnesium limestone including dolomite (with up to 40% of magnesium carbonate).

Group 1 produces a white lime, which when slaked and used in mortar can only gain strength very slowly by taking up carbon dioxide from the atmosphere and forming extremely slowly calcium carbonate, the starting material. Some other limestones, for example in groups 2 and 3, on the other hand, contain materials in addition to calcium carbonate, such as silica and alumina in various forms. The limes produced from these limestones are called hydraulic limes. The mortars made from them have considerable strength. These semi-hydraulic or hydraulic-lime will set under water. Their quality will depend upon the relative proportions of calcium carbonate, silica, and alumina present in the raw material, and the temperature at which they are burned or calcined.

White lime made by burning *Seep and Shankh* and by calcining high quality limestone (high content of calcium carbonate) is very pure. The lime produced by impure or dolomatic limestones is grayish white. There is also red lime "Kankar lime," which is made by grinding the calcined clay. The raw material and the type of lime produced is shown in the Table 1.2.1

1.2.3 Production of White Lime

In the ancient times the lime was produced by burning the raw materials in kilns or in earth ovens with wood serving as the principal fuel. Burning times varied from 30 hours to 7 days [Hassan, 1999, Alberti; 1912, Belidor: 1982, Forester; 1972, John; 1819]. Reactions possibly occurring between lime and wood ash or clay during the burning process in earth ovens gave hydraulic properties to the lime. There is very little information concerning burning temperature of lime. However, slow rising of the temperature to a low and constant level would have produced fine grained porous ancient lime. This would have gone intensive slaking, producing mortar with higher plasticity and good workability. Murray [Murray, 1956] also mentions that avoiding lengthy burning periods will produce a lime which is highly reactive, easily slaked and more abundant. Modern industrial lime burning maintains a standard time and a constant temperature which is higher than traditional kiln.

White lime is produced by calcining limestones. In this process limestone decarbonizes and turns into lime according to the following equations:

Sometimes limestone contains dolomite as impurity. This yields $\text{MgO} \cdot \text{CaO}$ and CaO after burning.



The dissociation of carbonate rocks is accompanied by an absorption of heat (1g mole of CaCO_3 require 190kJ of heat). The dissociation of calcium carbonate is appreciable at temperatures above 600 °C. Theoretically the minimum effective temperature for burning limestone is considered to be 800 °C. But in order to attain this temperature in the middle of the stone, an overall temperature of 1000 °C is necessary or very long time of heating.

Influence of Stone Size

The temperature distribution in the stone depends upon its geometry. In bigger stones, the temperature difference between the surface and the middle of the sample is greater than in the small size samples. It is shown in the Figure 1.2.1. Good quality of burnt lime is produced when the stone are crushed to small size (about 1.25 in.). This produces homogeneously burnt lime. Azbe [1954] has shown that the degree of calcination is directly proportional to the square root of the thickness (or average diameter in case of irregular shaped stones).

Influence of Stone Impurities

With the integral impurities in the stone at low temperatures (900-927 °F or 1670-1700 °F), relatively little silica and other impurities combine with lime. But as the temperature increases, the uncombined acid oxide impurities are increasingly absorbed, forming various complex calcium compounds, such as C_2S , C_3S , calcium aluminates, calcium aluminium ferrite etc.

A slagging effect occurs that tends to block the pores in the quick lime and thus slow down its reactivity. It means that when the lime is slaked, water penetration becomes more difficult in the interior of lime thereby retarding the hydration. As a result, lime abnormally high in impurities may react like a hard burned or recarbonated lime with water, even though over burning did not take place. Consequently, the presence of impurities is still another variable in lime burning.

An increase in temperature exerts a much greater influence on the dissociation rate than retention. Mather It is reported that an increase in temperature of only 50 °F (20 °C) exerts as much influence on the calcination as extending the burning time from 2-10 hours [Ray and Mather, 1928].

A porous lime usually has low shrinkage, whereas a dense lime of low porosity has higher linear shrinkage. When calcination temperature is increased or constant temperature in a medium to high calcination range is retained, there is diminution in the porosity. This phenomenon is very well

seen when the calcite cube was heated in hot stage microscope at 500°C and 1400°C (Figure 1.2.2. and Figure 1.2.3). In the Figure 1.2.3 it the shrinking is very clearly seen with the increase in the temperature. The reduction observed is about 15% [Murray, 1956].

In case of overheating (1000°C on the surface of the stones), the lime that is produced is over burnt "dead burnt" and is not of good quality. It does not react well with water and forms lump. In other case when it is calcined at 800°C , the temperature in the middle of the stone is lower and thus the stones are not well burnt. The product thus produced is a mixture of burnt and unburnt lime.

During firing, limestone decomposes and carbon dioxide is released (equation 1). It accounts for up to 44% of its mass, the volume of the product diminishes by approximately 10%, and, in consequence, the lime lumps produced acquire a porous structure.

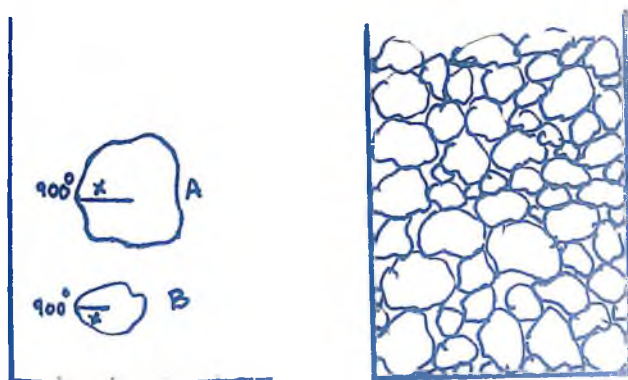


Figure 1.2.1 : Temperature gradient on the limestone during burning; if the temperature at the surface is 900°C , in the middle will be $900-X$, where X will depend upon the size of the limestone, in (a) X is more than in (b).

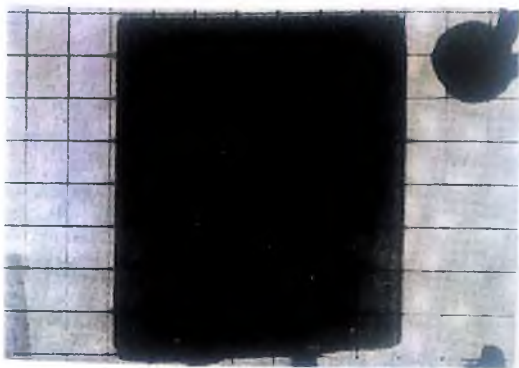


Figure 1.2.2 : Specimen of calcite cube as seen in heating microscope at 500 °C [Murray, 1956].

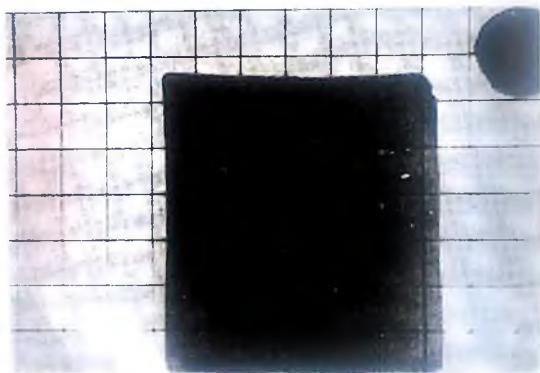


Figure 1.2.3 : Same calcite sample as in Figure 1.2.2 after being dead burned at 1400 °C causing visual shrinkage [Murray 1956].

Type of Kilns for Calcination

Calcination of limestone is done in two basic type of kilns ; the periodic, open or "flare" kiln (intermittent), and the draw tunnel, or running kiln (continuous). In the ancient period these were calcined in simple clamp kiln known as *Bhatta*. Later these were calcined using shaft kilns, fluidized bed reactors, flash burning furnaces etc. Most widely used are shaft shell type kilns, which are economical in fuel consumption but yield a lime contaminated with fuel ash.

Open Kilns: Early kilns were sometimes no more than simple clamps of alternate layers of stones and fuel. The stones were placed in such a way that there will be channels in between them. These were covered with mud with an opening for putting the fuel inside. The draft was thus created and warm air was circulated inside. It helped in the distribution of heat inside the kiln. It functioned as a down draft. The stones were burnt for particular period as specified by the skilled masons. Later the kiln was left unopened for a couple of days. The burning time was planned in such a way that the stones were not completely burnt. It was done intentionally and not because of the shortage of fuel and time. Thus the burnt lime contained calcium oxide (quick lime) + unburnt limestone (calcium carbonate). These are often built into the foot of the hill from which the limestone is obtained. This saves the transport cost. The stones thus can be crushed to about 1-1/2 inch gauge and fed into the kiln at a minimum labor cost. The walls of such kilns were often of the stone masonry.

Flare Kiln: In the flare kiln, as is shown in the Figure 1.2.4 [Davey, 1961], the limestone does not come in direct contact with the solid fuel but only with the heat and flames. This method is used mainly for calcining white chalk. It produces very evenly burnt pure white lime. To load the kiln, an arch of limestone lumps is made over a framework or hearth of iron bars and more limestone is added to fill it completely. In modern practice a coal or coke fire is started on the hearth beneath the rough arch. It gives the possibility to heat slowly first and later rapidly. It takes about 3 to 4 days to burn all the limestone, which is unloaded after cooling and reloaded.

Draw Kiln: In the simple type of draw tunnel or running kiln, alternate layers of moistened limestone and coal are packed up to the top of the kiln. It is shown in Figure 1.2.5 [Davey, 1961]. A fire is started at the bottom and as the lower layer of limestone becomes calcined the material falls through the grating at the base of the kiln from where it is withdrawn by shovel. New layers of limestone and fuel are put on the top and the process repeats.

It is in this way a continuous process. It takes about a week for the limestone to pass from the top to the bottom of the kiln, but the lime produced is not so pure and white and evenly burnt as in the case of Flare kiln. It may contain fuel ash. The temperature required for calcining the limestone is about 900°C and to attain this temperature when burning chalk to produce fat lime, 15 to 20% of coal by weight of the chalk is needed, and when burning hydraulic limestone about 25% coal is needed.

There are different theories. Some says that the heating was continued till $2/3$ of the stones were burnt, the other says that it was continued till $3/4$ th of the stones were burnt. The unburnt stones when milled and mixed worked like a very fine filler and partially as the pozzolanic material providing strength and enhancing the durability properties. This was the general practice used in the ancient period for making durable lime binders. Now a days for increasing the durability properties extra calcium carbonate powder is mixed [Green et al.1999] like a new invention.

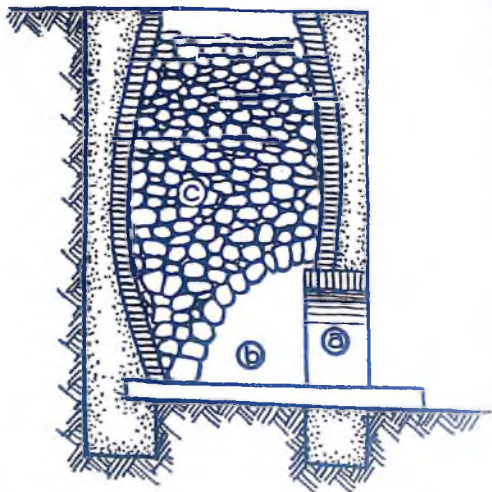


Figure 1.2.4 : Flare Kiln for calcining limestone, (a) Eye, (b) Fuel, (c) Limestone, [Dayey, 1961].

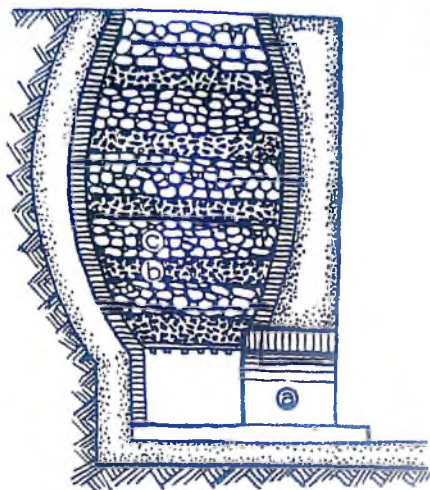


Figure 1.2.5 : Draw kiln for calcining limestone, (a) Draw hole, (b) Coal, (c) Limestone, [Davey, 1961].

Shaft Kiln: The shaft kiln consists of a shaft, a charging and a discharging arrangement and a blast. Blast is a means of air supply and gas exhaust (Figure 1.2.6). Limestone is charged into the shaft furnace in the batches or continuously from the top. As the lime is discharged, the column of the material descends, while hot combustion gases move in the opposite direction. In the shaft furnace three zones can be recognized; heating, burning and cooling zones. In the heating zone on the top of the furnace where the temperature is never held higher than 900°C ; limestone is dried, preheated, and organic impurities are burnt out. In the middle part of the furnace; in the burning zone the temperature lies between 900 and 1200°C . Here calcium carbonate dissociates with the evolution of carbon dioxide. In the bottom part of the furnace, the cooling zone; the lime is cooled by the air coming from below, from a temperature of 900°C to 50 or 100°C .

In these processes of burning limestone, fuel used is coal or cinder or wood, or cow dung cakes. These produce ash which comes out with the burnt lime from the furnace. These ashes are very fine and highly reactive.

They work like active pozzolanic materials. Thus the lime produced has some hydraulic properties. This lime gets higher strength when hydrated.

Wood and cow dung contains a lot of organic material together with high amounts of alkalis, i.e., sodium and potassium hydroxide. These work like a flux and helps producing the liquid phase at lower temperature. This can be the reason that some times even though the burning temperature was not so high vitrification is observed in the kiln fired with wood.

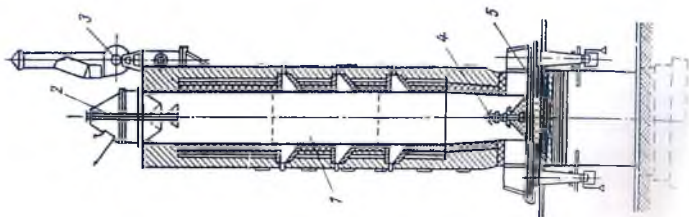


Figure 1.2.6 : *Shaft kiln for calcining limestone, 1) shaft, 2) charging device, 3) exhaust fan, 4) ridge type air supply device, 5) discharge mechanism [Komar, 1979].*

1.2.4 Production of Red Lime

Red lime: More popularly known as “Kankar lime” is made from special type of clay. It is unfertile (*User*) and is rich in iron. It is also called kankar. Kankar is not found every where. In ancient period, a proper survey used to be made to find the right type of kankar. The land was then purchased or a contract was given for supply of the kankar. The big pieces were dug from the land, broken into small pieces of approx. 1.5 inches and were piled in a rectangular form (*Chatta*) 10 x 5 feet and 13 inches high. These were kept till the end of the rainy season, during which the dust and loose clay is washed away. These were transported to the burning site on bullock carts. The money was paid per Chatta including the transport. Now a days the sand and gravels are carried on the horse back (Figure 1.2.7). It is a cheap and energy saving transport system.

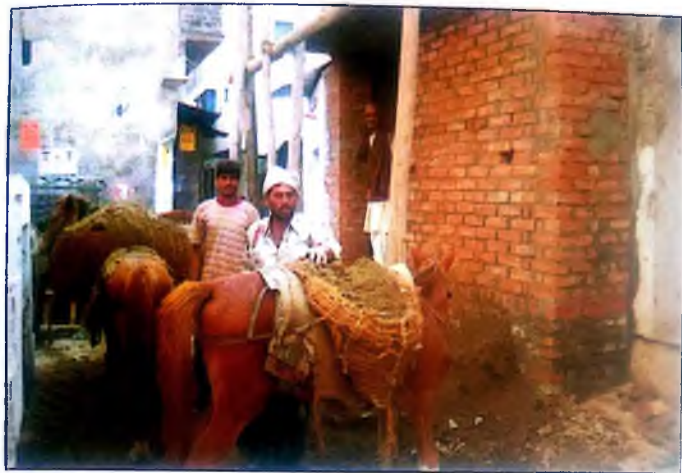


Figure 1.2.7 : S and is transported on the horse back [Photo, Chandra].

Open Bhatta, Hakim Saheb ka Bhatta, Lucknow

Kankar was calcined in a simple type of clamp kiln (*Bhatta*). The clamp kilns seem to have varied from area to area, depending upon local custom and the particular requirements of the lime. One such Bhatta, which was locally known as “*Hakim Saheb ka Bhatta*” [Hassan, 1999] from the town, Lucknow, capital of the state “*Utter Pradesh* “ is described here (Figure 1.2.8). The Kankar was laid on the ground in about 6 feet diameter and 8 to 10 feet height. There was an opening in the bottom for withdrawing the kankar. First of all cakes of cow-dung and wood are laid down. In Figure 1.2.9 making of cow dung cakes is shown. Over this is laid a 9 inch layer of kankar, followed by 3 inch layer of cinder till it reaches the requisite height. The burning time was 7 days. After 7 days the kankar was withdrawn from the bottom and new layers of kankar and cinder were fed from the top. After cooling the kankar was crushed to small pieces which later was milled to fine powder, bagged and sold.



Figure 1.2.8 : Schematic diagram of Hakim Saheb ka Bhatta, Lucknow, U.P., alternate layers of 3 inch cinder (a) and 9 inch kankar (b), with one opening for taking out burnt kankar.



Figure 1.2.9 : Making cakes from the cow-dung, [Photo, Chandra 1999].

Open Bhatta, Tapered

It is the same type of clamp kiln as is described earlier except that it is tapered. It means it has bigger diameter on the base and less on the top (Figure 1.2.10). The top layer is covered with mud.

Calcutta Type Kiln (Bhatta)

It is same like mentioned above except it is larger 8-10 feet in diameter and has opening from 3 sides instead of one (Figure 1.2.11). It was a very big kiln and could produce 50000 to 100 000 cu.ft.of Kankar in one time.

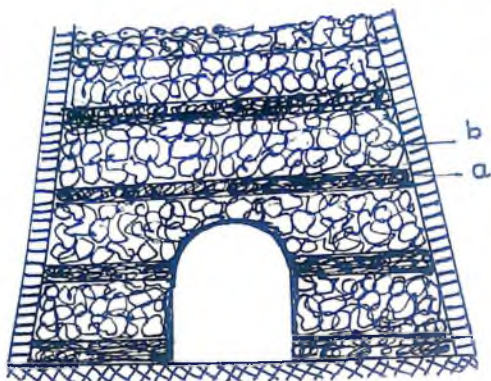


Figure 1.2.10 : Schematic diagram of tapered Bhatta, for calcining Kankar to produce red lime, alternate layers of 3 inch cinder (a) and 9 inch kankar (b), with one opening for taking out burnt kankar.

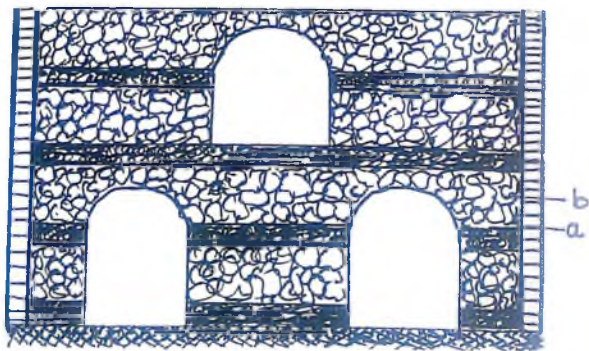


Figure 1.2.11 : Schematic diagram of Calcutta type Bhatta with 3 openings, for calcining Kankar to produce red lime, alternate layers of 3 inch cinder (a) and 9 inch kankar (b), with three opening for taking out burnt kankar.

1.2.5 Quality Control Test

Quality control test used to be performed on the spot. Two types of tests were done:-

1. Milled lime was mixed with water and a ball was made. This was put under water. If the ball did not disperse, it was certified as a good lime.
2. In another test, the lime paste thus made was filled in a glass bottle and left. If no cracks were observed on the side of the bottle, it was taken as good lime.

Lime produced in this way was of very good quality. 33 cu. ft. of this lime was required for joining 100 cu.ft. of bricks.

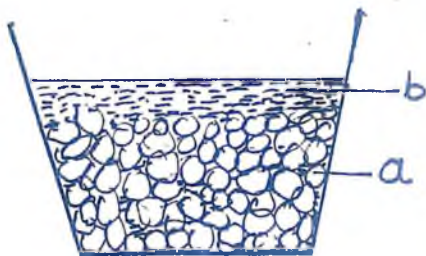


Figure 1.2.12 : Schematic diagram showing slaking of lime, (a) Burnt lime, CaO , (b) Water, H_2O .

1.2.6 Slaking of Lime

Lime slaking methods differed widely due to differences in lime type and to various purposes for which lime was intended to use.

Traditionally, lime was slaked in pits with abundant water, or covered with sand and slaked using only a small quantity of water. Alternatively the lime was cooled and left over a period of many years to slake naturally under the effects of rain water and atmospheric moisture. In some cases the lime was simply slaked before use or small quantities of quicklime were added to the mortar, slaking time varied from one month to ten years or more. Ancient methods of slaking can be listed as follows:

Slaking of lime alone

Slaking of lime with sand

Slaking of lime with natural polymers

Slaking of Lime alone

The building lime was prepared by slaking the burnt lime with plenty of water, which was later sieved in order to take away the lumps. During the process of slaking, hydroxides of calcium (and magnesium) are formed with a release of considerable amount of heat according to the reaction:-



One g-mol of CaO releases 65.5kJ of heat, and 1kg of quick lime 1160kJ. Traditionally, this process was carried out in pits and the slaked lime was left for several months or even years.

The temperature in the limestone pieces during burning was not the same. It varied from the surface to the core of the piece. It depended upon the size of the piece and the soaking time, and the time for which the temperature was kept constant. During this time actually, it is speculated that the difference in the temperature between the surface of the stones and the core will decrease. Even if the temperature becomes uniform from surface to the core, the degree of sintering will differ. It will be hard sintered on the surface and less sintered in the middle. It is mentioned in the Section 1.2.3. Besides, there are different theories about the burning time; some believe that the limestone was sintered till it was 2/3rd burnt and some believe that the sintering continued till the limestone was 3/4th burnt. In any case the stones after burning were a mixture of hard burnt (dead burnt), soft burnt and unburnt limestone lumps. The size and shape of the stone also varied. It is reported that slow rising of temperature to a low and constant level may produce fine-grained porous lime. This after slaking produces lime with higher plasticity and good workability. Further, it is reported that the avoiding lengths of burning periods produces lime, which is reactive, easily slaked and is more abundant [Boynton, 1961].

These stones after burning are put in the same pit for slaking. Now the big and hard burnt limestone, and limestone with burnt clay as impurity need much longer time for slaking compare to the time needed by the soft burnt crushed limestone. The lumps of unburnt limestone also takes much longer time to throw away its heat, decompose and will slake in water, producing the lime of the same consistency. When it is taken out not thoroughly slaked but fresh, it has little crude bits concealed in it, and so, when applied, it blisters. When such bits complete their slaking after they are on the buildings, they break up and spoil the smooth polish of the stucco.

Slaking and Particle Size of Hydrates

The particle characteristic of slaked lime depends upon the burning temperature, burning time and slaking conditions. It is reported that the hydrated lime particles will increase in size with longer burning time [Wittenben, 1980, Boynton, 1961]. Large amounts of slaking water will produce a coarser lime. Inadequate quantity of water will cause the lime to slake on the surface, whereas the lime depending upon the size of the stone will be less or not slaked at all. The type of lime produced also depends upon the amount of water added for slaking and the slaking time [Thorborg and Råman, 1985]. Lime slaked with small amount of water produces building lime, whereas abundant water and longer slaking time produces lime putty.

Different methods of slaking and use of varieties of quicklime produce hydrates of varying particle size, gradation, and surface area. All of which affect the quality and utility of the resulting hydrates. For most of the purposes fine particle size is preferred with a reasonably restricted size distribution. All + 30 mesh material, big cores and impurities are to be removed. General wet hydrates yield finer particles than dry hydrate from the same quicklime.

It is reported that the average particle size of dry hydrates can be reduced if the quick lime from which it is derived is pulverized finer [Adam 1927]. It is further reported that the putty volume is larger from soaking dry hydrate that posses the finest particle size. Slaking quick lime with a excess water improves dispersion of the hydrate particles, thereby contributing to finer particle size and slower settling qualities. Conversely insufficient or only slight excess of water causes an irreversible agglomeration of fine hydrate particle into coarse, rapid-settling hydrates of lower chemical reactivity [Whitman, Bonnel and Holmes, 1926, 1934, 1922]. It is concluded that the excess water, agitation, and increasing temperatures are advantageous to employ since (1) they reduce the tendency to agglomeration into large crystals and might actually promote faint deflocculation, (2) prevent local overheating of lime, and (3) increase the rate of hydration at any given temperature.

Slaking with Sand

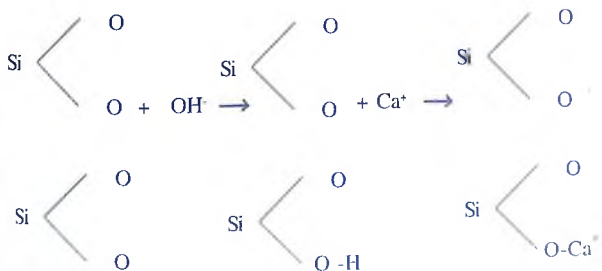
In ancient time the lime was slaked in pits with sand which was to be used later as mortar and plaster (Figure 1.2.12 and 1.2.13). It produces typical lime clumps but gives much better strength than the mortar made with well slaked lime. The reason behind this is expected to be as follows:

During slaking process there are sodium ions Na^+ , potassium ions K^+ , calcium ions Ca^{2+} and hydroxyl ions OH^- . The concentration of alkalies depend

upon their quantities in the limestone as impurity. The hydroxyl ion concentration in a saturated solution of calcium hydroxide is 0.04 molar (M) or $pH=12.6$; the pH of an aqueous solution is the logarithm of the reciprocal of the hydrogen ion concentration. The alkali in the lime can be high.

The surface of silica particles immersed in water show a weak acid character, which increases with increase in the surface area. The action is related to the degree of disorder of Si-O tetrahedra in the crystal structure of SiO_2 . In the alkaline environment, an acid base (Silica- calcium hydroxide) reaction takes place at the surface of the silica. Hydroxyl ions are absorbed onto the silica particles, and some of the silicon oxygen links are attacked. This weakens the bonding locally. The sodium and potassium cations then diffuse to maintain the electrical balance. They attract water to form gelatinous alkali metal ion hydrous silicate or alkali silica glasses. These finally interact with calcium hydroxide and produces calcium silicate hydrate, which is a binder. Thus the lime hydrated together with sand gets high strength and enhanced durability. Diamond *et al.*[1965] have studied the effect of lime on quartz. It is reported that "the lime attack on quartz produces CSH (gel) regardless of the experimental conditions".

In the initial stage water interacts with burnt lime and produces calcium hydroxide and some sodium and potassium hydroxide which may come from the impurities in limestone used for making lime. These hydroxide ions subsequently interact with silica (sand) and forms basic surface on the aggregates. Under alkaline conditions, calcium ions react with the basic silica and deposit calcium ions on the aggregate surface to form calcium silicate.



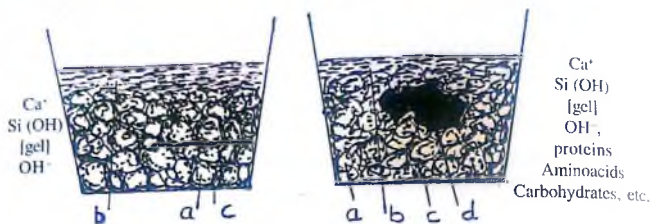


Figure 1.2.13 : Schematic diagram showing slaking of lime (i) with sand, (ii) with dead cat (natural polymers), a) burnt lime, b) water, c) sand, d) natural polymer.

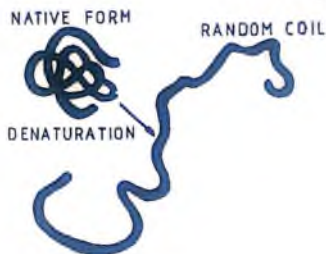


Figure 1.2.14 : Denaturation of protein, [Chandra et al. 1987].

Slaking time governs the degree of reaction and the stability of the calcium silicate hydrate formed. CSH are of three types; CSH I, CSH II, and CSH (gel). The most stable of this is CSH II. As is the law of nature; "longer the stone will be in nature, closure it will be to the stability" longer slaking time will produce dense, stable CSH II which will give high strength and durability.

Slaking of Lime with Natural Polymers

Natural polymers: Agro- products are mixed with lime and slaked together. It is said that the lime is also slaked with dead animals like dead cat. The interaction of agro-products and the dead animal is very similar. The

interaction of natural polymers and lime are discussed in detail in the Chapter 4.

Natural polymers contain proteins, carbohydrates, fats and some metals. Animals body constitutes of protein, nitrogen compounds, amines, fat, and calcium phosphate which builds up the skeleton and metals. When an animal is dead, the body disintegrates. Amines and fats are hydrolyzed forming amino-acids. The proteins denaturize.

Proteins have a coil structure (Figure 1.2.14). Which constitutes of hydrophobic and hydrophilic parts. During the denaturisation the coil opens and more hydrophobic and hydrophilic parts are exposed. Hydrophobic part goes to the air phase and the hydrophilic part goes to the water phase. For example in the case of interaction with calcium hydroxide, the hydrophilic part make complexes with the Ca^{2+} and the hydrophobic part makes the pores and capillaries water repellent. The interaction of protein with calcium hydroxide is well described by Chandra and Aawik [1987].

Fats are mixtures of various glycerols which are esters of glycerine and fatty acids. When these are hydrolysed, the fatty acids become free from the esters. These fatty acids may interact with calcium hydroxide making complexes. Interaction of vegetable oils with calcium hydroxide produced during portland cement hydration has been studied by Chandra and Xu [1995]. It is shown that the vegetable oil addition increases the water repellency.

It is a saying that

“ When a dead cat is thrown in the pit for slaking the lime, lime produced is of very good quality”.

When a dead cat is thrown in a slaking pit for lime, the reaction becomes similar to the one occurs with the addition of natural polymers. Various components as are named above come in contact with the hydrating lime. Divalent calcium ions interact with the amino acids and proteins and make complexes as explained (Figure 1.2.13).

Proteins in addition to make complexes with calcium also influence on the crystallization process. One of the examples is the formation of Aragonite and Vaterite during the carbonization of calcium hydroxide.

Oyster shells and conch are found by the sea side. Chemically these are calcium carbonate with a chemical formula CaCO_3 . But they have different crystal structure. Three polymorphs of CaCO_3 exist in nature: Aragonite, Calcite and Vaterite. Calcite is the stable form at room temperature and pressure, and Aragonite and Vaterite are unstable. There are also proteins in Oyster shell and Conch together with the CaCO_3 . What

actually is the function of these proteins is out of the scope here. Proteins influence upon the formation of Oyster shells and Conch. These are water repelling materials. It may be that the water repelling characteristic comes due to the complex formation of proteins with calcium. Besides, it influences upon the crystallization process when calcium hydroxide carbonates. In one of the studies made by Su and Heuer [1999], a protein "Strombus gigas" was extracted from a giant Pink Conch. This protein can induce the formation of Aragonite and Vaterite.

Su and Heuer have grown a substrate on a chitin/silk by the reaction of $(\text{NH}_4)_2\text{CO}_3$ and CaCl_2 , without any proteins. The product formed was only calcite with a very well defined cubic structure. Whereas in the presence of the soluble proteins extracted from the Aragonitic shell of *Strombus gigas* Vaterite and Aragonite were also produced. Flakelike structure of vaterite and the fibrous structure of Aragonite is shown in the Figure 1.2.15.

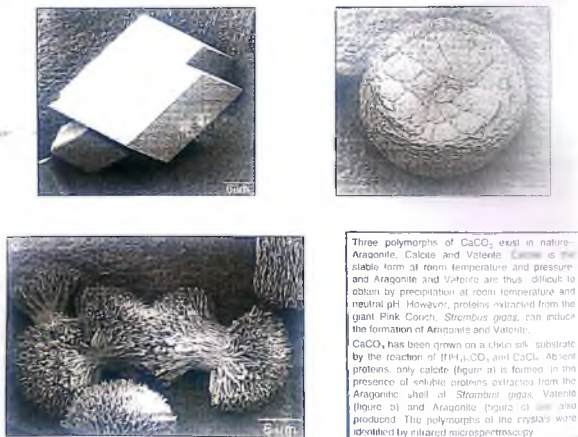
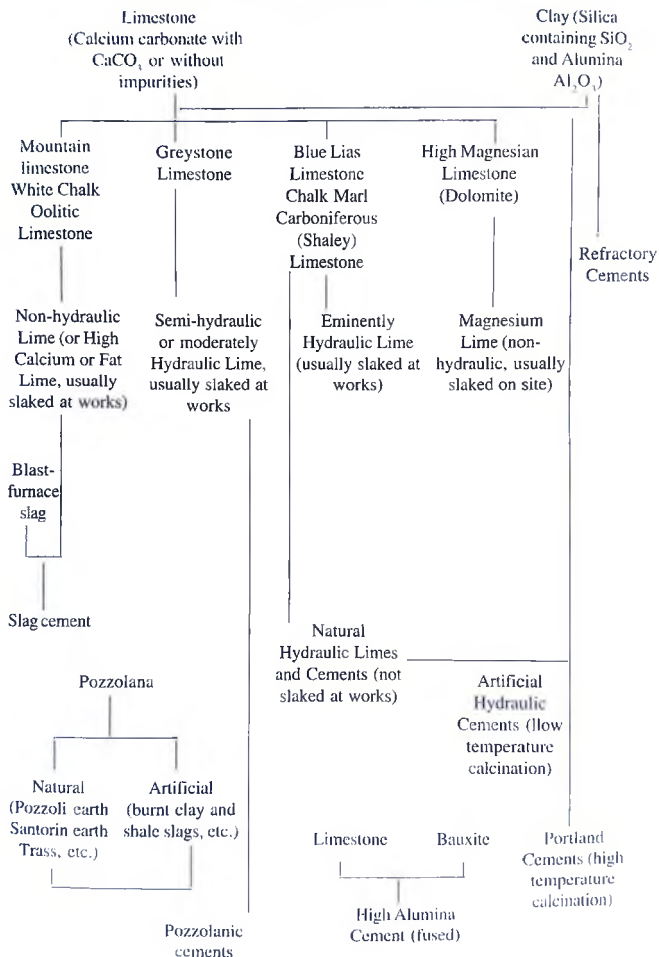


Figure 1.2.15 : Crystal Structure of Calcium carbonate produced with and without protein (A) calcite-no protein, (B) and (C) with protein: strombus giga-Vaterite, and Aragonite [Su and Heuer, J. Am. Cer. Soc.1999].

Table 1.2.1 : Raw materials and the type of lime produced [Davey, 1961]

PRODUCTION OF BUILDING LIMES AND CEMENTS



Maturity of Lime

The maturity of lime is tested in the following way:

Take a hoe, apply it to the slaked lime in the mortar bed just as you hew wood. If it sticks to the hoe in bits, the lime is not yet tempered, and when the iron is drawn out dry and clean, it will show that the lime is weak and thirsty (needs more water and slaking); but when the lime is properly slaked, it will stick to the tool like glue, proving that it is completely tempered (Figure 1.2.16).

Prolonged slaking enables the stones burnt to different degree to hydrate to the same degree. It produces well hydrates uniform mass. Besides the hydration in chemical terms; transformation of CaO to Ca(OH)_2 , hydration time also influences the crystal structure of Ca(OH)_2 . Longer slaking time ensures more stable crystal structure. It enhances the growth of plate like crystals of calcium hydrate known as Portlandite. Further it improves the plasticity of the lime putty.

In the ancient period, the lime slurry (putty) was slowly passed through the steps. By so doing the bigger particles, lumps which were left in slaking stayed behind on the steps while the fine slurry went down. Now a days lime putty is sieved through a 5 mm screen. Thus the bigger lumps are removed.

Old lime putty, which was protected from the air in a pit or bin, acquires a rigidity similar to gelatin. When this rigid mass is worked through and “knocked up”, it becomes workable and plastic again. This property is very specific for the non-hydraulic lime putty. Therefore it is important that the hydraulic setting materials are not to be knocked up after they begin to stiffen.



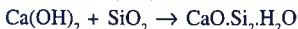
Figure 1.2.16 : Lime sticking to the inverted trowel, showing well maturity, [Scotish Lime Report 1995].

1.2.7 Hardening

Lime hardens when the calcium hydroxide come in contact with carbon dioxide from the air, or in the case of mortar when mixed with sand it makes CSH as is explained before.



Slaked lime (soft) \rightarrow Carbonated lime (Hard)



1.2.8 Carbonation

Ney [1967], among others, describes the carbonation process of lime mortar occurs in two stages;

1. Calcium hydroxide changes to calcium carbonate (Carbonation in the presence of moisture and carbon dioxide).
2. Water rich in carbon dioxide dissolves part of the calcium carbonate formed in the first stage to form soluble calcium bicarbonate. The dissolved calcium bi-carbonate reacts with Ca(OH)_2 and forms CaCO_3 which recrystallizes with a lowering in the moisture or rise in the temperature. This recrystallization will bring about an increase in the size of the crystals and will bind them more tightly together.



Carbonation in two stages gives greater strength and tightness to the lime mortars than a single stage process. Frequent rapidly repeated changes in the mortar moisture content will facilitate the dissolving-precipitating process. Which is contrary to the cement base mortars.

During the hardening shrinkage occurs due to the change in the volume. Slaked lime is never used alone, but always with a filler in order to avoid shrinkage cracks.

1.2.9 Chemical Interactions during Hardening

Here two cases are discussed; 1) When only lime is used as a binder and in the second case; 2) When lime -pozzolana or lime-pozzolana and clay are used as binder.

In the first case carbonation takes place during the hardening process, and in the second case carbonation as well as pozzolanic reactions take place simultaneously.

The hydration process is shown in Figure 1.2.17 for lime and in Figure 1.2.18 when pozzolana is mixed with it. It is seen here that the cycle is complete. That is starting from limestone of undesired shape, it is possible to make stone of the desired shape. This is the natural mineral found in nature. It is therefore stable in a wide range of environmental condition.

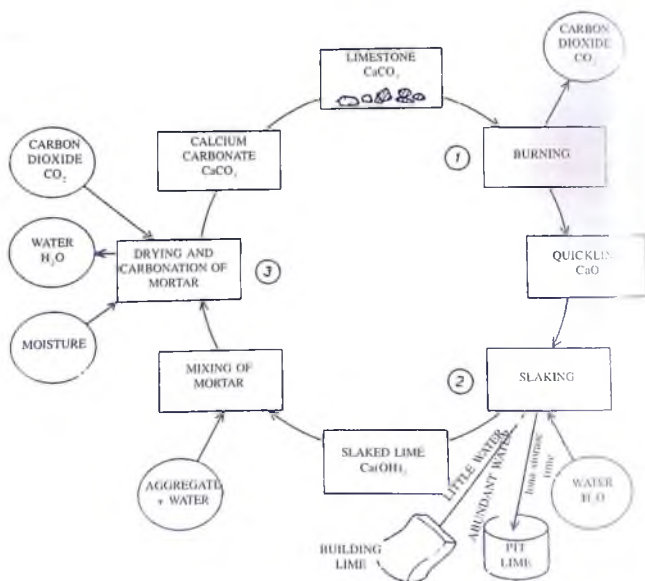


Figure 1.2.17 : Lime cycle.

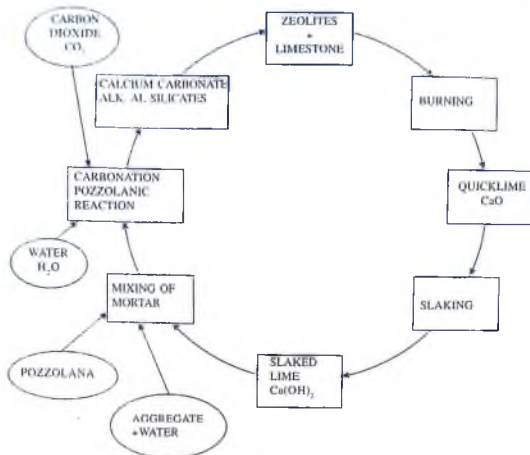


Figure 1.2.18 : Lime-Pozzolan Cycle.

1.2.10 X-Ray Diffraction Analysis of Lime

Some of the limes made from oyster shells, conch, gravel and limestones were analyzed by X-ray diffraction. The x-ray diffractometer used was Siemens 5000. The tests were performed using Ni filter and Cu K α radiation. Lime was mixed with sufficient quantity of water for hydration and was left in the room for one month. The lime before hydration and after hydration was analyzed by x-ray diffraction spectroscopy. The X-ray diffractograms are shown in the Figures 1.2.19-1.2.22.

Lime from Oyster Shell

The lime made from Oyster Shell (Figure 1.2.19) is very pure. All the peaks belonged to calcium hydroxide; Portlandite. After hydration, there was little carbonation which is shown by some peaks of calcite, a stable phase of calcium carbonate; CaCO₃ and aragonite; a less stable phase of calcium carbonate.

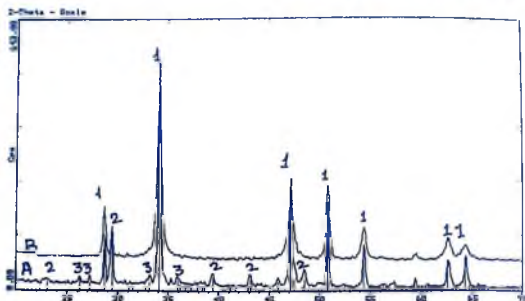


Figure 1.2.19 : X-ray diffractogram of lime made from the Oyster Shell; (A) Hydrated, (B) Unhydrated; 1. Portlandite, $\text{Ca}(\text{OH})_2$, 2. Calcite, CaCO_3 , 3. Aragonite, CaCO_3

Lime from Conch

The lime made from Conch has shown the same mineralogical phase as of the one made from oyster shell (Figure 1.2.20). All the peaks belonged to Portlandite. After hydration the portlandite and calcite peaks were observed.

Though the lime made from oyster shell and conch originate from the similar source, their chemical composition is the same, but their mineralogical composition is different. After hydration the amount of portlandite is less here compared to the oyster shell, calcite is significantly lower, and aragonite is missing altogether. These differences can be due to the difference in their crystallization process, which is influenced by proteins present in oyster shell and conch.

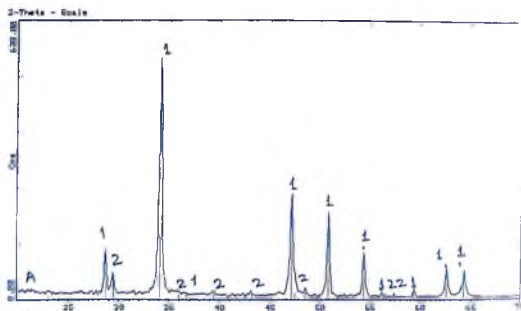


Figure 1.2.20 : X-ray diffractogram of lime made from Conch, (A) Hydrated; 1. Portlandite, $\text{Ca}(\text{OH})_2$, 2. Calcite, CaCO_3 .

Lime from Limestone

The lime from limestone has shown calcium hydroxide; Portlandite as the dominating phase, followed by Larnite; a calcium silicate, Ca_2SiO_4 and calcium carbonate; Aragonite and calcite (Figure 1.2.21).

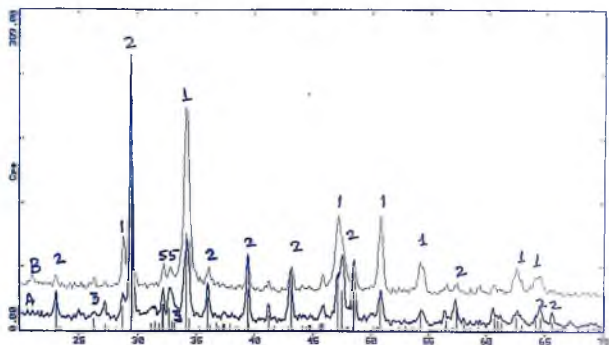


Figure 1.2.21 : X-ray diffractogram of lime made from Limestone.

(A) Hydrated, (B) Unhydrated; 1. Portlandite, $\text{Ca}(\text{OH})_2$, 2. Calcite, CaCO_3 , 3. Aragonite, CaCO_3 , (5), Larnite Ca_2SiO_4 .

In the lime made from limestone the major part is well crystalline calcium hydroxide $\text{Ca}(\text{OH})_2$ “Portlandite”. It also contains substantial quantity of calcium carbonate, CaCO_3 “Calcite” and not significant amount of calcium silicate, Ca_2SiO_4 “Larnite”. Calcium carbonate might be due to the unburnt limestone and calcium silicate from the impurity in the limestone.

Lime from Gravel

In the lime from gravel, dominating phase is calcite, CaCO_3 , followed by Portlandite, $\text{Ca}(\text{OH})_2$, Larnite Ca_2SiO_4 , and traces of Gehlenite, $\text{Ca}_3\text{Al}_2\text{SiO}_7$. It shows that the gravel contained clay minerals with composition of calcium silicates and calcium aluminum silicates. (Figure 1.2.22).

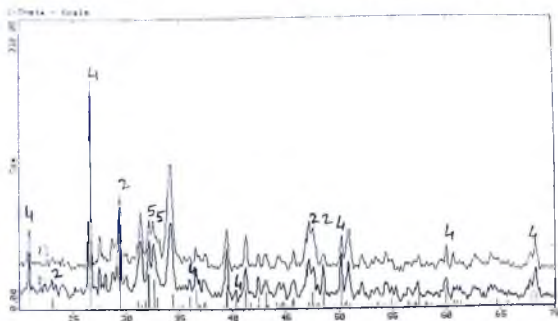


Figure 1.2.22 : X-ray diffractogram of lime made from gravel; (A) Hydrated, (B) Unhydrated; 2. Calcite, CaCO_3 , 4. Quartz SiO_2 , (5), Larnite Ca_2SiO_4

Red Lime

The red lime obtained by burning *kankar* contains calcite CaCO_3 , Quartz, SiO_2 , Albeit $\text{NaAlSi}_3\text{O}_8$, ordered, Albeit calcium, $(\text{Na}, \text{K}, \text{Ca})\text{Al}(\text{Si}, \text{Al})_3\text{O}_8$, Anorthoclase; disordered, and Magnesiosadangaite; $\text{KCa}_2\text{Mg}_5(\text{Si}_7\text{Al})\text{O}_{23}(\text{OH})_2$ (Figure 1.2.23). The difference between the red lime and white lime is that in the red lime silicate compounds are present as the dominating phase whereas in the white lime there are oxides and carbonates. It alone does not have so much hydraulic property. It comes under the group semi-hydraulic. But it works very good like a pozzolanic material when mixed with some white lime. Red lime is cheaper than the white lime in India, and is used for pointing and for plastering after mixing with a little white lime and water.

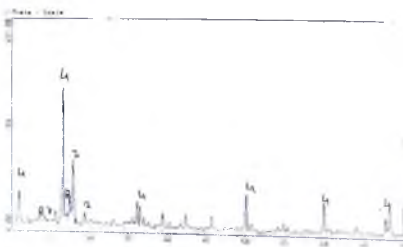


Figure 1.2.23 : X-ray diffractogram of red lime; (A) Hydrated, (B) Unhydrated; 2. Calcite, CaCO_3 , 4. Quartz SiO_2 , (5), Larnite Ca_2SiO_4 , 7. Albeit calcium, $(\text{Na}, \text{K}, \text{Ca})\text{Al}(\text{Si}, \text{Al})_3\text{O}_8$, 8. Anorthoclase.

1.2.11 Scanning Electron Microscope Analysis

The microstructure of limes made from oyster shells, conch, gravel and limestones as analyzed by X-ray diffraction (Figures 1.2.19, 1.2.20, 1.2.21, 1.2.22), were analyzed using Energy Dispersive Low Vacuum Scanning Electron Microscope (ESEM). The microphotographs are shown in the Figures 1.2.24, 1.2.25, 1.2.26, and 1.1.27 for limes made from oyster shells, conch, gravel and limestones respectively.

Lime from Oyster Shell

The microphotograph of the lime made from Oyster Shell (Figure 1.2.24) is a mixture of crystals of different geometrical configuration. AS is revealed from XRD analyses (Figure 1.2.19) it is a mixture of Calcium hydroxide; Portlandite which has hexagonal flakes structure, calcium carbonate, calcite, which has a hexagonal or trigonal structure and calcium carbonate; Aragonite which has a fibrous structure.

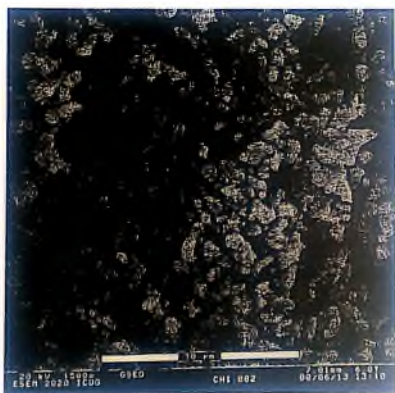


Figure 1.2.24 : ESEM micrograph of lime made from Oyster shell.

Lime from Conch

The microphotograph of lime made from Conch (Figure 1.2.25) shows a crystal structure constituting of hexagonal flakes of Portlandite and Rhombs of calcite. These are in agreement with the minerals identified by XRD (Figure 1.1.20).

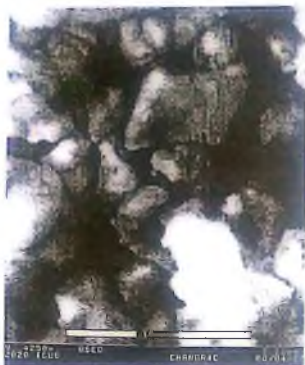


Figure 1.2.25 : ESEM micrograph of lime made from Conch.



Figure 1.2.26 : ESEM micrograph of lime made from Limestone.



Figure 1.2.27 : ESEM micrograph of lime made from Gravel.

Lime from Limestone

The micrograph of lime from limestone (Figure 1.2.26) shows a crystal structure which is a mixture of hexagonal flakes (Portlandite), rhombs (calcite) and elongated plates of calcium silicate hydrate (CSH). These are in accordance with the results obtained by XRD analyses (Figure 1.2.21).

Lime from Gravel

The micrograph of the lime from gravel (Figure 1.2.27) does not show crystals of distinct morphology. It is a clump of needles and flakes. But as is revealed by XRD analyses (Figure 1.2.22) the presence of quartz (tri-prisms), calcite (hexagonal or trigonal) lathes could not be seen. Only the fibrous bundle of calcium silicate “larnite” is seen which is in agreement with the XRD results.

1.2.12 Stabilization of Lime

Lime base building materials are not very durable. Their durability is increased by stabilizing them. The stabilization is done by physical and chemical

treatment. Physical treatment is by slaking lime for longer time. It is described in the section 1.2.6. Chemical stabilization is done by the addition of organic and inorganic materials. The inorganic materials used for stabilization are known as pozzolanic materials. These will be described in the following Section 1.3. The other type of stabilizers used are organic materials which are described here.

In the ancient period the organics used for stabilization were natural materials available in nature. The materials used were the same as described in “*stabilization of soils*”, Section 1.1.2. The reaction takes place here also by cation exchange. The divalent calcium ions interact with the carboxylic groups, formed by the hydrolyses of the organic material and form complexes. These complexes are stable and durable in different environmental conditions. A list of the natural organic materials used and their mechanism of interaction are described in the Chapter 4 “*Natural Polymers*.” The interaction of lime with different chemicals is very well described by Chandra [1994].

These additions do not only interact chemically, they also modify crystal structure. Big crystals of Portlandite with preferred orientation are not formed, instead small crystallites are formed which coalesce to each other and form agglomerates. Thus the crystal structure contains a lot of homogeneously distributed crystallites instead of big portlandite crystals accumulated at places and making pockets (Figure 1.2.28) [Chandra, 1994]. These calcium complexes, if are not sufficient to fill up the pores and capillaries in the pore structure, they at least seal them. Thus the chemical additions do not only modify the crystal structure they also modify the pore structure. More pores, small in diameter are produced instead of less pores of bigger diameter. Thereby, the porosity of the material may be the same, but its permeability will significantly be decreased. Consequently the strength and the durability properties will significantly be enhanced.

1.2.13 Uses of Lime in Building Materials

The practical uses of lime, which are of the most interest for building purposes, are in connection with limewater, limewashes, plasters, mortars and concrete.

Lime water

Lime water is made by adding lime to water and stirring. Allow the lime to settle so forming a saturated solution. This is used by a soft brush over the limestone masonry.

Lime Plasters

Plaster is defined as a material used in a plastic state to form a durable finishing coat to the surfaces of walls and ceilings of a building. It is described separately in Chapter 6.

Lime Mortars

Lime mortars are the mixtures of sand, lime, pozzolanic materials, additives and water. It is described in Chapter 7.

Lime Concrete

These are the mixtures of sand and larger aggregates with hydraulic limes, pozzolanic materials, additives and water.

Concluding Remarks

Lime was produced in the ancient period using different raw materials depending upon their availability, like the sea shales and conch were used in the places close to the sea so as to have easy access whereas Kankar was used in the places where there was good quality (*Usseer land*: non fertile land) of clay and limestone close to the limestone quarries. Their mineralogical composition and crystal structure varied with the variations in the raw materials. The purity of lime produced varied according to the impurities in the raw materials. In the ancient period lime was burnt using simple type of burning technique. There was no homogenous temperature in the kilns and thus the lime produced was a mixture of burnt, semi burnt and unburnt lime. Burnt lime worked as binder where as unburnt lime worked as fine filler. The impurities in the raw materials; limestone reacted during the burning process with lime and produced hydraulic compounds. Slow rising of temperature to a low and constant level will produce fine grained porous lime.

The properties of the hydrated lime depend upon the slaking process: lime slaked alone, lime slaked with sand and lime slaked with the addition of natural polymers. The best results were obtained in the last case when the lime was slaked with sand and the natural polymer. The lime produced had good adhesion properties and enhanced durability properties.

1.3 Pozzolanic Materials

Pozzolans are the materials without hydraulic properties but are capable of hardening as a consequence of their reaction with calcium hydroxide and

water. The family comprises both natural materials, which have been used for thousand of years, and artificial materials, such as fly ashes, silica fume, metallic slag burnt clay, of more recent use. The family of the pozzolans include materials of widely varying composition. All of them except the burnt clay are very rich in silica.

Lime mortars were generally used in the ancient period as the sole binder. But these had slow hardening and low durability. These problems were overcome by using pozzolanic materials and natural polymers. It was discovered that the non-hydraulic lime could be made hydraulic by the addition of suitable materials which will interact with the burnt lime and produce the silicate products which have the binding ability, and will give early strength. Such material are known as pozzolanic material.

In recent years interest has been developed to determine why ancient concretes are so much more durable than the concretes of today [Davidovits, 1987]. Carbonation of lime produced during the hydration results in volume change of cement matrix (10-11%), and is assumed to have negative effect. It is very controversial statement. In ancient cements, however, this degree of carbonation has not been deleterious to the durability and strength of concrete. Some of these concretes look like hard natural stones even today after 9000 years.

Ancient concrete in Roman structures has remained unaffected by severely corrosive conditions, such as flowing water and salt laden air, in a period of two thousand years, whereas modern portland cement concrete has suffered extensive damage in the same conditions in a period of ten years. One of the example which can be cited is the rehabilitation of the Roman baths in Tiberia where Portland cement concrete has been used. The structures restored by using Portland cement concrete have been dramatically damaged by hot solutions, while the two thousand year old Roman concrete remains unaffected [Malinowski, 1961]

Analyses of some of the ancient lime-pozzolanic concrete from Italy, Greece and Cyprus done by X-ray diffraction showed calcite as the predominant crystalline phase together with some weak crystalline phase of analcime, $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot 2\text{H}_2\text{O}$.

The binding properties of the ancient cements are due to the production of calcium silicate hydrates (C-S-H gel), which are colloidal precipitates and have a varying composition. The chemical composition of these cement significantly differs from that of Portland cement due to the presence of a very high amount of amphoteric oxides (Al_2O_3 , Fe_2O_3), acidic oxides (SiO_2) and the presence of oxides of the alkaline metals sodium and potassium. It

entire cycle. In subsequent developments, it was found to be more efficient to set up batteries of several kilns with staggered operation cycles. In this manner the output was more or less continuous.

Thattai and Patel [1978] have discussed the utilization of a vertical shaft kiln process for the production of burnt-clay pozzolana; some details of the kiln and process are shown in Figure 1.3.3. The feed consisted of a mixture of clay lumps 50 to 100mm in size and coal slack (consisting of 48% ash, 31% fixed carbon and 20% volatiles). The condition of calcination were 700°C for 3 hours; this was monitored by using thermocouples and controlled via the air blower and feed input. The plant shown in the Figure 1.3.3 has a capacity of 10 ton.

The National Building Organization in New Delhi now known as the National Council of Building Materials Research [Sen Gupta and Rao, 1978] has developed a fluidized bed process for the production of burnt clay pozzolanas. In this process, the soil to be calcined is sun dried, then pulverized and screw fed into the top of the kiln. As the material falls, its progress is impeded by fins attached to the side of the kiln which allow intimate contact with the updraft of hot flue gases generated by oil burners. The calcined material passes through the burning zone and exits the furnace where it is allowed to cool. The contact time with the hot gases is extremely short, of the order of a few minutes, but is apparently enough to calcine the clay feed.

All methods of production have in common the requirements to grind the pozzolana once it has been calcined. This is conventionally done in either ball or hammer mills in association with classifiers and various forms of collectors. Some calcined materials are very soft and require minimal grinding, calcined Kaoline for example. Other soils, because they have constituents which are not affected by the calcination temperatures, may take several hours to produce material of adequate fineness. While it may be expected that the reactivity of the pozzolana would increase with fineness, the water requirement to achieve normal consistency will also increase- This consequence will be detrimental to potential strength development, as the water to cement ratio will increase. Also the energy requirement for ball milling normally constitute about 25 to 30% of the cost of producing calcined soil pozzolanas and the should be minimized where feasible.

Chatterjee and Lahiri [1967] have investigated the relationship between pozzolanic activity and specific surface for burnt clay pozzolanas. Although a few details are available, the results shown in Figure 1.3.4 are of interest because they show that pozzolanic activity increases with fineness, as would be expected, and that clay calcined at different temperatures but ground to

the same fineness have different reactivity. It is apparent from the results presented that the clays tested have begun to crystallize beyond 800°C . As a result, when these pozzolanas are ground to the same fineness so that of a pozzolana calcined so that the clay structure is quasi-amorphous, its pozzolanicity is comparatively less.

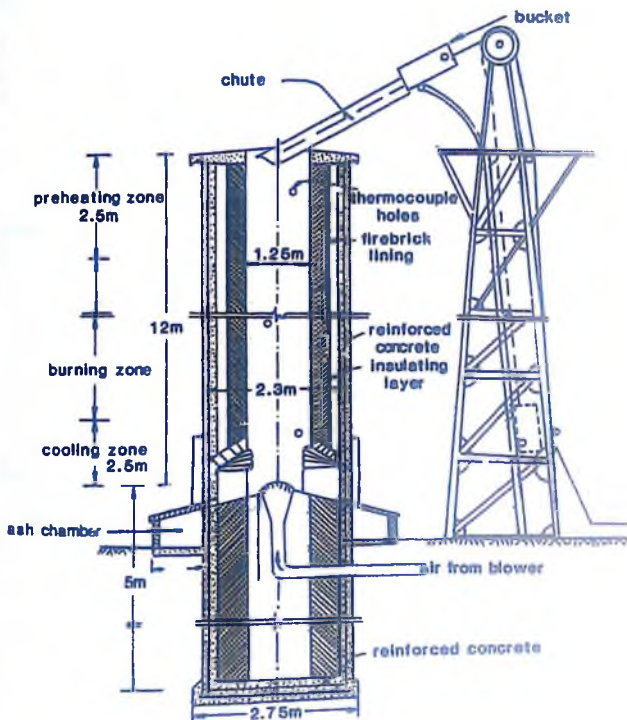


Figure 1.3.3 : Vertical shaft kiln for calcining clay, [Thate and Patel, 1978].

the material by oxide ions at the apexes of the tetrahedron. At the surface, however, the oxide ion is converted to a hydroxyl group, that is



This destroys the equilibrium of the unit within the material and allows it to pass into the lime solution where it reacts with the calcium ions to form insoluble calcium silicate hydrates. The removal of one silica unit permits another to be at the interface between the material and the solution and thus the mechanism can continue. Sersale considers that this mechanism can occur more easily in pyroelastic pozzolanas because the bonds between the silica tetrahedra are weaker. For zeolitic pozzolanas, the reaction would accelerate when the solution penetrated into the open structure. Finally the mechanism would explain the faster rate of reaction of finely divided and porous pozzolanas.

Takemoto and Uchikawa [1980] consider that the pozzolanic particles are protonically attacked by water in the highly alkaline lime solution, dissociating the Si OH group on the surface of the particle to SiO^{4-} and H^{2+} . As a result the particle surface is negatively charged and absorbs Ca which causes alkalis in the pozzolana to dissolve into the liquid phase. The Ca^{2+} at the particle surface reacts with silica and alumina to form a film or layer which thickens with time. Osmotic pressure which develops from the difference of concentration between the inside and outside of the layer causes it to rupture. As a result of differences in the diffusion characteristics of the calcium aluminate and calcium silicate hydrates, calcium aluminate hydrates precipitate away from the pozzolanas while the calcium silicate hydrates are found at the surface of the pozzolana. Takemoto and Uchikawa refer to the mechanism as diffusion-controlled dissolution.

Drazaj *et al.* [1978] support the mechanism proposed by Takemoto and Uchikawa [1980]. They found that the reaction consisted of the diffusive dissolution of the zeolite mineral and lime and that the reaction was limited by the diffusion of calcium and hydroxyl ions through the C-S-H and the interface layer of the zeolite. They observe that the C-S-H was formed at the surface of the zeolite at the beginning of the reaction (at seven days). In summary, they considered that the mechanism was a typical topochemical process.

Sersale however believes that the process is not topochemical "since the hydrated phases appear after the disintegration of the silica-alumina network in the glass". It is not clear from Sersale's surface dissolution mechanism where the hydrate products are formed. However the

final set time is not achieved. It is likely that the reactivity of the pozzolana is weak and the specified strength requirements may also not be attained. The features of four standards for testing lime-pozzolana mixes are shown in Table 1.3.3. It can be seen that the Indian and ASTM methods use accelerated curing regimes while the DIN standard requires a longer curing temperature. For the LP40 grade in the Indian Standard the strength requirements are similar to both the ASTM and DIN specifications; the Indian standard however permits two lower grades.

The optimum lime pozzolana ratio from the strength point of view is between 1:2 to 1:3.

Besides the hydraulic properties which the pozzolanic material impart, it also modifies the pore structure partly due to the pozzolanic reaction and partly due to the filler effect of the fine particles of pozzolanic material. Consequently the porosity and permeability decreases thereby the absorption properties of the material which governs the durability properties.

The addition of pozzolanic material significantly reduces the alkali-aggregate reaction, and improves the resistance to the sulphate and chloride attack.

Since the pozzolanic reaction is slow, the properties like permeability and porosity decrease with time, which means the material becomes more durable with time.

Portland-Pozzolana Cements and Concrete

In general, substitution of portland cement reduces the strength at early ages but the comparative difference reduces at later ages. Using Surkhi as a cement replacement, Uppal and Mohinder Singh [1955] showed that at 90 days, mixes containing up to 15% surkhi gave about 92% of the strength of the control mix. However an increase in the amount of replacement to 20% resulted in a strength reduction to 82% of the control (at 90 days).

For the Bhakhra dam project using a montmorillonite shale calcined in a rotary kiln, Khanna and Puri [1957] showed that with a 20% cement replacement there was no difference in strength reduction relative to the control at one year and for 25% replacement the strength reduction was only 7%.

Bhardwaj *et al.* [1980] investigated the effect of calcium chloride in concrete containing surkhi as a cement replacement. tests were carried out using dosage rates 2,3, and 4%. Direct replacement of cement for surkhi was not made; 10% of the cement was replaced with 20% surkhi, 20% cement was replaced with 30% surkhi, and 30% cement was replaced with

40% surkhi. The results indicated that for 20% cement replacement mix with a dosage rate of 3% calcium chloride, the strength characteristics essentially matched those of the control mix, particularly after 28 days.

The permeability of concrete containing a calcined pozzolana is less than that of the plain portland cement concrete. It further decreases by curing through the pore refinement. Calcined pozzolanas have the same tendency as other pozzolanas in reducing expansion due to the alkali-aggregate reaction.

1.3.6 Influence of Admixtures

Research conducted by the Central Road Research Institute in India [1968] indicated that for a burnt -clay pozzolana, an addition of 3% by weight of gypsum was optimum in accelerating early strength development. At 28 days, for a lime-pozzolana mortar (lime: pozzolana:sand, 1:2:9) the strength was 12% greater than control series; however at 3 days the strength was 64% greater. In addition to gypsum, sodium chloride, sodium carbonate, sodium silicate and plaster of paris had been investigated as potential accelerators. While sodium silicate gave significant improvements at 3 days (more than 200% for 3 and 4% by weight of sodium silicate), the 28 days strengths were comparable or less than the control series (depending upon the amount of sodium silicate added). In a second series of tests, calcium chloride and sodium hydroxide were included. Sodium hydroxide was not effective as accelerator and calcium chloride was inferior to gypsum at dosages rates exceeding 2%.

Concluding Remarks

Research is going on the development of the method and technique for using industrial by products like fly ash, silica fume, blast furnace slag, still there is continued demand of calcined pozzolana in India. It is very good that this way the old tradition will be maintained and the technique of its use known by the ancient builders will not vanish. It will help a lot in the restoration and conservation work to reproduce the repair material of the same or similar quality.

1.4 Gypsum

Gypsum is a mineral and rock. The name of the mineral is calcium sulphate dihydrate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, but sometimes the term gypsum is used to include all minerals constituting of calcium sulphate irrespective of the amount of

water of crystallization attached to it. Apart from the $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, hemihydrate $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$ or anhydrite II can also be seen.

1.4.1 Phases in the $\text{CaSO}_4\text{-H}_2\text{O}$ System

The $\text{CaSO}_4\text{-H}_2\text{O}$ system consist of three major forms with different water of crystallization. The dihydrate has two waters of crystallization, the hemihydrate has only half water of crystallization and the anhydrite has none. The dihydrate is found in one form whereas the hemihydrate exists in two forms: α and β - hemihydrate. The α and β forms have different crystal habits and specific surface areas. α -hemihydrate crystallizes in well- formed large crystals, whereas the β -hemihydrate crystallites are very small.

Three types of anhydrides have been reported, soluble anhydrite: AIII, natural anhydrite; AII and insoluble anhydrite; AI. The AIII, which is formed by dehydration of the hemihydrate, exists in three stages, namely β -AIII, α -AIII^o and β -AIII. Anhydrite II is formed at higher temperatures from Anhydrite III or hemihydrate and is identical to naturally occurring anhydrite. Anhydrite II exists in three stages: namely AII-s (slowly soluble anhydrite), AII-u (insoluble anhydrite), and AII-E (Estrichgips). Because the AII-phase has a slow to very slow reaction with water, activators are often used. Different phases of gypsum are presented in the Table 1.4 and the transitions between the phases in the Figure 1.4.1.

1.4.2 Natural Gypsum

Calcium sulphates found in nature is termed as natural gypsum. Most common amongst them are the dihydrate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and anhydrite (CaSO_4).

The bulk weight of pure dihydrate is about 2300 kg/m^3 , its hardness on Mohs scale is between 1.5-2.0 and its color is white or colorless. Generally the commercial dihydrates are not so very pure and contains impurities. The usual impurities are clay, slate, anhydrite, chalk, dolomite, silica and iron compounds. The color is influenced by the impurities, and can be brown, grey, pink or red., depending upon the particular impurities present.

The bulk weight of pure anhydrite is about 3000 kg/m^3 , its hardness on Mohs scale is 3.0-3.5 and its color is white. Like dihydrate its color also varies depending upon the impurities present. It can be grey, blue, red or brown.

Table 1.3.3 : Details of Specifications for Lime Pozzolana Mixes [Cook, 1985].

Standard	Type of pozzolan	Specimen size(mm)	Mix design, lime:poz:sand	Determination of water content	Curing	Strength requirement
ASTM C593	Any	50 cube	1:2:8.22	Flow method Flow, 65-70% 10 blows in 6s	2 days 54 °C then 23° until test	7 days 4.1 MPa, 28 days 4.1 MPa
ISI 727/ 1344	Burnt clay	50 cube	1:2M:9	Flow method Flow, 110+/-5% 10 blows in 6s	2 days 27 °C 8 days 50 °C	4.9 MPa
IS 4098	Lime pozzolan	50 cube	1:3**	Flow method Flow, 110+/-5% 10 blows in 6s	7 days 27 °C 21 days 27 °C	LP40 LP20 LP7 7 d 2 1 0.3 28d 4 2 0.7
DIN 51043	Trass	160 x40x 40 prisms	1:4:7.5	Constant 0.45X (trass + lime)	28 days 20 °C	5 MPa

s.g pozzolana

$$*M = \frac{\text{s.g lime}}{\text{s.g pozzolana + s.g lime}}$$

** lime + pozzolana:sand

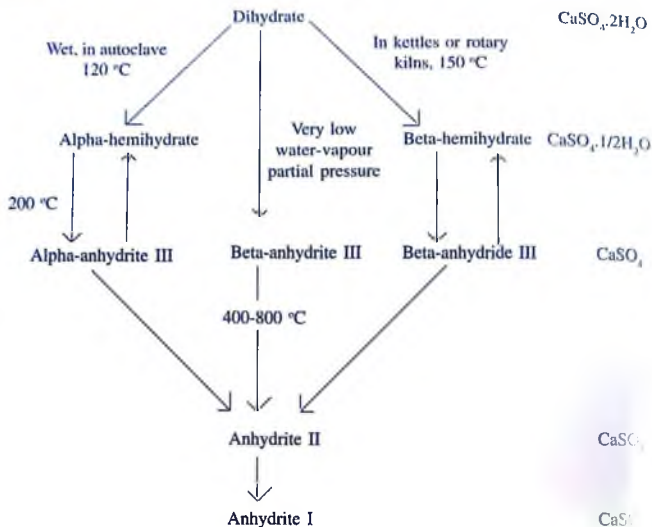


Figure 1.4.1 : Phase transition in the CaSO_4 system.

Genesis

Different types of crystalline minerals are produced on the partial or total evaporation of inland seas and lakes. The process may be summarized as follows:

There are soluble salts in the sea water which crystallizes with the evaporation of water. This occurs in stages which is related to the solubility of the salts. The most soluble salt precipitates last. In general the first salt to separate from the sea water by evaporation are carbonates. When the water has been evaporated to 19 percent of its original volume, calcium sulphate starts to separate. Depending upon the temperature, pressure and salinity of the solution, calcium sulphate may be deposited in the form of gypsum or anhydrite.

Gypsum deposits may also occur as a result of volcanic activity, manifested as an accumulation of sulphuric acid (produced from sulphide minerals, such as pyrite), which converts calcium carbonate into sulphate. This kind of gypsum is less exploitable than the evaporation deposits.

In the rock deposits, there are calcium sulphate sand dunes, formed through weathering of gypsum rock, and a soft mixture of gypsum and clay (gypsite), apparently the result of recrystallization of gypsum by separation from nearby deposits. Other less frequent varieties of gypsum are: *Alabaster*, a compact and massive, marble like material with a very fine crystalline structure used since antiquity for statuary and since the middle ages for interior decoration; *Selenite*, a transparent crystalline materials, used in antiquity for window panes; *Satin spar*, a Satin like fibrous material, also occasionally used for decoration and copy, an efflorescence-like material, found on saline deposits in Australia.

Mining and Preparation

Gypsum is mined from the surface or near the surface deposits by quarrying. This is the most common form of mining. Deposits that occur at depth are developed by underground mining. Most surface deposits are covered by overburden which must be removed before the gypsum can be quarried. Overburden that exceeds 5 meters in thickness is commonly removed by large drag-line scrapers. Lesser thickness of overburden are removed by combined shovel-truck or tractor-scraper operations and bulldozing. Gypsum quarries are usually developed by benching.

Underground gypsum deposits are mined by standard methods. The width or depth of gypsum mined is dependent on the thickness and purity of the seam. Crude gypsum from the quarry or mine, which may measure up to 1 meter in size, is reduced to about 150 mm by automatic crushers.

Impurities in natural dihydrate are for example mud, silt, dolomite, limestone and anhydride. The percent of dolomite, limestone or anhydride is minimized by selective mining or quarrying, and large pieces may be removed by sorting at the quarry face. Mud and silt may be reduced by coarse crushing followed by washing and screening.

Differentiation between dihydrate and anhydride is crucial for the gypsum industry. For plaster of Paris manufacture, for example, the purity of the dihydrate is of prime importance: a maximum dihydrate content is desirable since the presence of anhydride may actually jeopardize the production process or impair the quality of the product. But in some cases, depending on the desired product, a certain presence of anhydride may even be beneficial.

The preparation of gypsum depends upon its end use. In some plants the material is milled and ground to powder without any further treatment. This is used in cement industry.

The rest is calcined to remove part of the water of crystallization and form hemihydrate. Calcining is the industrial term for dehydration of gypsum to hemihydrate or to other partially or completely dehydrated calcium sulphate phases. The chemical formula of hemihydrate is $\text{CaSO}_4 \cdot 0.5 \text{H}_2\text{O}$.

1.4.3 By-Product Gypsum

Gypsum is also formed as by-product [Rozcielniaski, 1996]. Two groups of gypsum by products have been identified; chemical gypsum and desulphogypsum. The first is produced by chemical processing, the second originates from the flue gas desulphurization, installations in power stations. The compositions of the by-products differ substantially, primarily with respect to impurity content. Chemical gypsums are contaminated with the raw materials used in particular technologies, as well as the products of chemical processes. These contaminants affect the properties of by-product gypsum and subsequently formed binders.

The desulphogypsum produced by the wet process is highly pure calcium sulphate dihydrate. Some impurities do not influence the reactions of the $\text{CaSO}_4\text{-H}_2\text{O}$ system. However, if the SO_2 sorbing agent is introduced to the flue gas stream without de-dusting or directly to the furnace, complex desulphurization products are formed. The products are mixtures of calcium sulphates with different water contents, calcium sulphide, along with significant amounts of fly ash or fly ash with bottom slag.

1.4.4 Production of Sulphate Binder

The $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ dehydration is a basic process in the production of gypsum binders, depending upon the parameters of the process, the following types of gypsum materials are formed, $\alpha\text{-CaSO}_4 \cdot 0.5 \text{H}_2\text{O}$, and $\beta\text{-CaSO}_4 \cdot 0.5 \text{H}_2\text{O}$, anhydrite II or Estrich-gypsum.

Gypsum plasters are made by heating gypsum mineral or selenite at 125°C . During heating about 75% of its water of crystallization is lost. The production of gypsum plaster is shown by a schematic diagram in Figure 1.4.2.



The hemi-hydrate is the major component of plaster of paris which is prepared by heating the hydrate at $150\text{-}160^\circ\text{C}$. Plaster of paris sets very quickly when mixed with water and forms hard solid mass consisting of

Table 1.4.1 : The $\text{CaSO}_4\text{-H}_2\text{O}$ Phases [Näsman, 1989]

	<i>Calcium sulphate dihydrate</i>	<i>Calcium sulphate hemihydrate</i>	<i>Anhydride III</i>	<i>Anhydride II</i>	<i>Anhydride I</i>
Formula	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	$\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$	CaSO_4	CaSO_4	CaSO_4
Molecular mass(g/mol)	172.17	145.15	136.14	136.14	136.14
Thermodynamic stability °C	<40	Metastable*	Metastable*	40-1180	>1180
Form of stages		Two forms $\alpha\text{-HH}$ $\beta\text{-HH}$	Three stages $\alpha\text{-AIII}$ $\beta\text{-AIII}^*$ $\gamma\text{-AIII}$	Three stages AII-s AII-u AII-E	
Other names	Gypsum, Raw gypsum, Set gypsum, Hardened gypsum	α -form, Autoclave plaster, α -plaster β -form, stucco, β -plaster, plaster of paris	Soluble anhydride, $\gamma\text{-CaSO}_4$, Dehydrated hemihydrate	Raw anhydride., Natural anhydride, Anhydride; Calcined anhydride, Dead burnt gypsum, $\beta\text{-CaSO}_4$	High temperature anhydride anhydride $\alpha\text{-CaSO}_4$

Contd.....2

Table 1.4.1 : The $\text{CaSO}_4\text{-H}_2\text{O}$ Phases [Näsman, 1989]

	<i>Calcium sulphate dihydrate</i>	<i>Calcium sulphate hemihydrate</i>	<i>Anhydride III</i>	<i>Anhydride II</i>	<i>Anhydride I</i>
Synthesis conditions (°C and atmosphere)	<40	α -form >45, from aqueous solution β -form 45-200, in dry air	α -AIII and β -AIII 50 and vacuum or 100 in dry air β -AIII* 100 in dry air	20-1180	>1180
Production temperature	<40	α -form 80-180 β -form 120-180	α -AIII and β -AIII 290 AIII .110	300-900 AII-s>500 AII-u 500-700 AII-E>700	Not produced commercially

*Metastable in air saturated with water vapor.

interlaced crystals of gypsum. There is expansion during the hydration of gypsum. The rate of setting is related to the condition under which the heating was performed.

There are two types of hemi-hydrates α and β . These differ in their crystal structure, and properties.

α - Hemihydrate

It is called the crystalline hemi-hydrate. It is formed by heating at high pressure in the presence of water vapor in an autoclave. It is well crystallized and is not very porous. It is not very reactive and reacts very slowly with water.

α - $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$ can be produced by phosphogypsum dehydration in liquid medium in hydrothermal conditions or at the atmospheric pressure in the solutions of salts. The Giulini method is one of them where the preliminary washed phosphogypsum is subjected to the autoclaving at 105 - 140°C . The phosphogypsum is slurried in water. The suspension of phosphogypsum is then subjected to floatation and subsequently pumped to a buffer tank. From the buffer tank, the material is transported to the scrubbing tower and, after introducing the nucleating agent, passes to the autoclave for $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ dehydration. The suspension containing α - $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$ formed in autoclave is centrifuged at 90 - 100°C to separate the excess liquid phase. The hemi-hydrate is washed with hot water and dried at 90°C . The production of $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$ following the Guilinin method can also be carried out without autoclaving, in concentrated solutions (e.g 1% KCl + 23% CaCl_2) near the boiling point.

β -Hemi-Hydrate

It is called the micro-porous hemi-hydrate. It is formed in a dry atmosphere. Its crystals are smaller and contain pores of relatively large dimension. It reacts more freely with water.

The hydration reaction is exothermic. The heat evolves when it comes in contact with water. Setting is accelerated by adding gypsum dust or salt and is retarded when glue or starch are present.

If the hydrate (or the hemi-hydrate) is heated above 165 - 170°C the remaining water also evaporates and anhydrous calcium sulphate is formed. It may rehydrate, but very slowly.

Transformation of hydrated gypsum into anhydride can take place spontaneously in dry hot climate. As a result the mechanical strength of gypsum plaster can be sharply decreased. Calcium sulphate is slightly soluble

in water. Thus it is not normally used on the exposed surfaces in damp climates.

When the dihydrate is heated above 200°C it loses all its crystal water. It then does not recombine with water and is said to be "hard burnt", when it is heated above 1200°C it decomposes.



1.4.5 Uses

Natural gypsum is widely used in the construction, manufacturing and agriculture industry. Here the use of gypsum in the construction industry will only be discussed.

Dihydrate, It is used as Portland cement set regulator, soil conditioner. Apart from working as set retarder gypsum addition also increases its resistance to sulphate attack. For this dihydrate or anhydride rock, or a mixture, is directly added to the cement clinker (4-6%) before grinding.

These are also used as soil stabilizer. During this process they supply calcium and sulphur, to neutralize sodium chloride, and to stabilize nitrogen. Dihydrate also improves the physical structure of certain soils by breaking up compacted clays. This increases their porosity and improves the drainage.

Both dihydrate and anhydride can be used to produce cement and sulphuric acid. For this, the dihydrate is mixed with coke, sand, clay, and ash and fed to a kiln. The calcium sulphate is reduced to calcium oxide and sulphur dioxide. The calcium oxide forms cement clinker and the sulphur dioxide is used to make sulphuric acid. These of course are very expensive processes and do not draw commercial attention.

β-hemihydrate is generally called stucco or plaster of Paris. Huge quantities of Hemihydrate is used in Plaster boards. Gypsum ceiling tiles are also produced from β-hemihydrate, water and small amount of water. It is also used for flooring.

α-hemihydrate requires only 2/3 as much water as β-hemihydrate to form a workable slurry. This requires less time for drying and the product is denser and harder. α-hemihydrate is used for self levelling floor screeds [Mailvagnam, 1996], statuary casting, plaster for molds in ceramic industry, orthopedic plaster and dental plaster.

Gypsum was used both as a mortar for joining the blocks and as a plaster already at the beginning of the third millennium B.C in ancient periods in India, Mesopotamia etc. (see section 5: Plasters and section 6: Mortars).

By the second half of the eighteenth century it came to be more generally used for wall and ceiling plasterwork, and various patented varieties were

introduced such as Keens Cement (1838) and Parian Cement (1846) [Brereton, 1995]. Apart from other properties gypsum plasters are fire resistant.

Keen's cement is a commercial product closely related to Estrich gypsum, sometimes used for molding stones. It is produced by heating gypsum to about 900°C and combining it with accelerators which induce rapid hardening after water addition. The hardened material takes a high polish and has a relatively high density that resembles marble. The resemblance to natural marble often. This can be further improved by the addition of pigments.

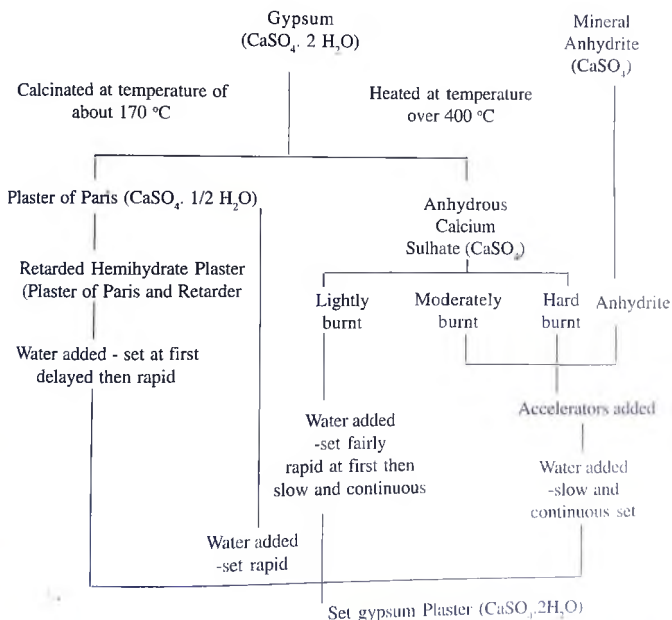


Figure 1.4.2 : Schematic diagram, showing the production of Gypsum Plaster.

Concluding Remarks

Gypsum occurs as a natural mineral as well as it can be produced synthetically. The natural mineral $\text{CaSO}_4 \cdot \text{H}_2\text{O}$ consists of three major forms with different water of crystallization. The dihydrate has two water of crystallization; the hemihydrate has half and anhydrate has none. The dihydrate exist in one form and the hemihydrate in two forms, α and β . These have different crystal behavior and specific surface area.

Gypsum is used as set retarder in Portland cement manufacture. α -hemihydrate is used for self levelling floor screeds, statuary casting, plaster for molds in ceramic industry, orthopedic plaster and dental plaster.

Gypsum was used both as a mortar for joining the blocks and as a plaster already at the beginning of the third millennium B.C in ancient periods in India, Mesopotamia etc. By the second half of the eighteenth century it came to be more generally used for wall and ceiling plasterwork, and various patented varieties were introduced.

1.5 Cements

There are natural and artificial cements. The natural cements are actually lime-pozzolan materials or made with ground mountain rocks and caustic alkalis. The first ones were known as "Roman Cements" [Grouding and Halstead, 1954] and the second ones are known as "Soil cements". In 1796 James Parker of Northfleet patented Roman Cement, which was produced by calcining the nodules of argillaceous (clay-rich) lime-stone called "Septaria" at a temperature around 800°C . These cements are characterized by their color and their quick set which might be as little as half an hour. The soil-silicate cements were launched as Geopolymers in USA in 1970's and were patented in 1976 by Davidovitz [Davidovitz, 1976]. The composition of this cement is a blend of kaolin, oxides of calcium, magnesium and soda (natron).

Until the middle of the nineteenth century the term "cement" generally referred to "Roman Cement". Since then the term "Cement" has commonly been understood to mean "Portland Cement". Composition of these so-called Roman cements were variable, but usually they contained between 45 to 65% of calcium carbonate, and up to 55% of clay, silica, iron etc. Besides the Portland cement "Soil Cements" have also been developed, the hydration products of which are more analogous to the minerals found in the earth crust.

1.5.1 Soil Cements

The soil cements are produced by mixing well ground mountain rock with industrial wastes dissolved in caustic alkalis and salts of sodium and potassium. They resemble to the natural zeolites of the type $R_2O \cdot RO \cdot R_2O_3 \cdot (2-4) SiO_2 \cdot n H_2O$. Formation of these compounds are analogous to the minerals found in the earth's crust; like zeolites, mica, hydrous mica, which at high temperatures crystallize to nepheline and feldspars. Their production process is similar to the natural processes of mineral and rock formation. The concrete produced by using this type of binder is called "Soil Silicate Concrete". These were developed and exploited by The Kiev Institute of Civil Engineering, Ukraine [Glukhovsky, 1959, 1967].

The idea of using such minerals in binding systems is associated with the fact that the earth's crust is mainly composed of rock forming minerals based on calcium-potassium-alumino silicates with remarkable properties, in particular high resistance to atmospheric pollution and acid rain. The soil cement contains a significant amount of alkalis (Na_2O , K_2O from 3-20%) and caustic alkalis KOH. The oxides of alkaline soils do not exist in the system or sometimes they are added in the form of or together with metallurgical slags and the existing calcium binders. In the first case the binder is alkaline. The structural formation bonds in this case are supplied only by alkaline alumina-silicate types, sodium or sodium-potassium zeolites, mica and hydrous mica. In the second case the binders are alkaline soils having a bond of C-S-H gel and consisting of the above mentioned alkalis or a combination of alkali-alkaline soil alumino-silicates.

These binders have revealed the possibility of obtaining hydraulic hardening without depending on hydration with water containing a high content of basic calcium minerals like C_3S , C_2S , C_3A , C_4AF , but depending on the hydration of the compound with low basic alkali and alkaline soil alumina silicate systems, and also by means of the dispersion of low-basic calcium and possibly with pure alumina silicate compounds in solutions of caustic alkalis.

Natural mineral binders are based on the principle that hydraulic hardening takes place only with the use of compound elements belonging to the second group in the periodic table (Mg, Ca, Sr, Ba) i.e alkaline earth metals with complex formation in the third (aluminium), fourth (silicon), fifth (phosphate) and sixth (sulphate) groups. The capacity to hydrated hardening is possessed by compounds having elements from the first group (Li, Na, K, Cs, Rb) of alkaline metals with pairs of complex formation in the third and fourth (alumina-silicates), second and fourth (alkaline earth silicates), second and third (alkaline earth aluminate) groups.

Production of Soil Cement Binders

Binders of this type can be produced in the following way: By burning the limestone CaCO_3 , dolomite $\text{CaCO}_3 \cdot \text{MgCO}_3$ and kaoline. During the burning kaoline transforms to meta-kaoline ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$) acquiring pozzolanic properties, while the dolomite or the carbonates of calcium and magnesium form oxides (CaO , MgO). When adding silica and also natron (Na_2CO_3) or its mixture with potash (K_2CO_3) and dissolving the mixture with water, NaOH and KOH are formed, which activate the reaction process of the mixed compounds and thus result in the synthesis of geopolymers like analime and hydro-sodalite.

The same results can be achieved by using unburnt kaoline in the mixture with lime [Ca(OH)_2] or natron (Na_2CO_3). The addition of such a system containing kaoline and limestone produced a concrete [Davidovitz, 1967], the structure formation bonds of which are non carbonate materials present both in the concrete of pyramids of *Cheaps and Chefren*, and in some cases hydro-sodalite ($\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$), analcime ($\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot 2\text{H}_2\text{O}$), and other calcium and hydrous sodium aluminosilicates and Ca(OH)_2 which gradually carbonises to calcium carbonate (calcite). With these researches the concretes used in the ancient period was no longer secret, and it is possible to produce them today.

Soil cements in which the composition of the newly formed structure is a result of the synthesis of some mineral systems were discovered and officially registered and patented more than 30 years ago [Davidovitz, 1957-58]. Soil silicates and in particular the slag alkaline concretes based on them are being produced since 1962.

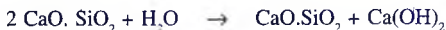
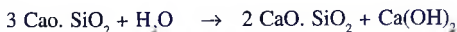
1.5.2 Portland Cements

These are man made cements and are produced by calcining a mixture of clay and limestone at a very high temperature approximately 1350°C . These cements possess the hydraulic properties and produce high strength in combination with water. One of the most popularly known and used cement is Portland cement. It was developed and patented by Aspdin in 1821 in England. Its color resembles the color of the stone Portland, thus it was named as Portland cement. The approximate composition of Cement is;

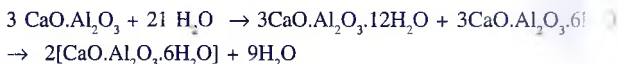
Calcium oxide	CaO	50-60%
Silica	SiO_2	20-25%
Alumina	Al_2O_3	5-10%

Magnesium oxide	MgO	2-3%
Ferric Oxide	Fe ₂ O ₃	1-2%
Sulphur tri-oxide	SO ₃	1-2%

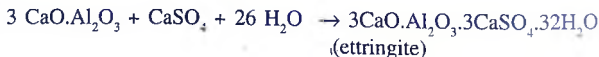
The mineralogical composition of the clinker is C₃S, C₃A, C₄AF and CS. These hydrate when come in contact with water and produce calcium silicate hydrate, calcium hydroxide, calcium aluminate hydrate, calcium aluminum ferrite hydrate. Tri-calcium aluminate hydrate when reacts with gypsum CaSO₄ it forms ettringite, and monosulphate. The hydration reactions are shown below by the chemical equations;



Tri-calcium aluminate hydrates according to the following equation in the absence of sulphate ions;



More relevant to Portland cement hydration is the reaction of 3CaO.Al₂O₃ with the sulphate ions present as gypsum which are added to control the flash set potential of tri-calcium aluminate. The reaction proceeds as follows;



This ettringite further reacts with the calcium aluminate and is converted to monosulphate 3CaO.Al₂O₃.CaSO₄.12H₂O

As is seen here during the hydration process and hardening the final products are not those starting minerals which were calcined for making the cement. These are also not the minerals which are found in nature. Thus these do not have natural balance, and consequently are not stable. The cement cycle is shown in the Figure 1.5.1.

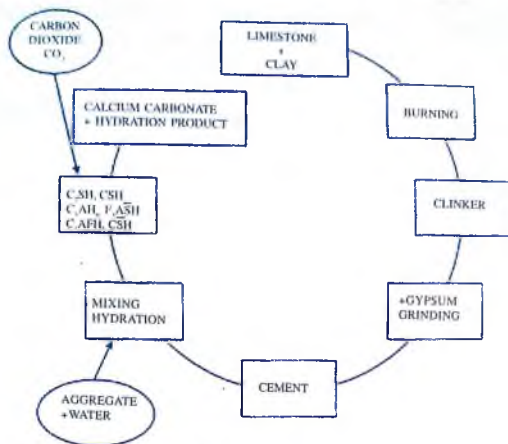


Figure 1.5.1 : Cement Cycle.

Unlike lime base binders where the final products after hardening are the starting minerals which were used for making the lime Portland cement does not produce the final hydration product which are the starting minerals. This is the main reason of long time durability of structures made using lime base material compare to those made using Portland cement base material. In the case of lime early strength is low. It increases with time. Subsequently the other properties like porosity and permeability decreases with time. In a way it can be said that the durability of the lime base structure improves with time. Whereas in the case of Portland cement one achieves early high strength; about 85% of the ultimate strength after 28 days. That means what happens, it mostly happens after 28 days. Portland cement is not suitable for use in the traditional mortars and plasters on historic buildings.

The drawbacks of Portland cement are given below:

Portland cement does not contain only calcium aluminum silicates, but also calcium sulphate and some alkaline salts formed when clays or fuels containing sodium or potassium are used in the calcining process. The alkali content of normal cement can be very high. Consequently several soluble or partially soluble compounds are formed during the hardening process of Portland cement, Calcium hydroxide, sodium hydroxide, sodium silicate with different sodium to silica ratio, calcium sulphate etc. If the liquid in which the reaction takes place is allowed to migrate into the neighboring porous

materials (as might happen in the structural repair of old masonry) the structure can be damaged due to the following reasons;

- i) Dark spots can appear because of the action of alkali on some sandstones and limestones.
- ii) Semi-insoluble efflorescence of silica and calcium carbonate can be formed.
- iii) Stronger crystallization stresses can be generated by sodium sulphate; a very soluble salt.

The Drawbacks of Portland Cement

The drawbacks in the use of Portland cement for repairs and restoration of historical buildings are as follows;

1. It is too strong in compression, adhesion and tension, so that it is not compatible with the weak materials of historic buildings. It is another thing that such a weak material have very high durability.
2. Because of its high strength it lacks elasticity and ductility when compared with the lime mortar, thus passing greater mechanical stresses on adjacent materials and thus causing their early deterioration.
3. It is dense and has low porosity. Thus it hinders the moisture transportation. Consequently it is not good for curing damp walls. In fact the reverse is true. For if used, it only drives moisture upwards. When used as mortar its low permeability accelerates frost damage and increases internal condensation.
4. It shrinks on setting, which develops cracks. Water or salt solutions may penetrate through these cracks and due to the low permeability of the cement mortar it can not migrate outside. It makes the wall surface more wet for the first and for the second the salt solution moves around inside the structure causing severe damages.
5. It produces soluble salts on setting which may dissolve and damage porous structure.
6. It has high thermal conductivity and can produce cold bridges when used for injections in consolidation of structures.
7. Its color is too dark and the structure very often is too smooth. These characteristics are aesthetically incompatible with traditional material

1.5.3 Comparison of Lime Mortars with Cement based Materials

Lime mortars and harlings can absorb water and subsequently allow it to evaporate from the building. Cement based materials are more brittle and

less porous and this brittleness can lead to cracking and water penetration. By inhibiting evaporation, hard dense mortars tend to trap moisture (from sources such as wind driven rain penetration, capillary action and rising ground water) within the structure, leading to a built up of moisture in the building fabric. This in turn can reduce the thermal performance of the wall and will encourage the development of timber decay and other moisture related problems.

Because lime mortars are vapor permeable and allow a structure to breathe their use is particularly important in buildings constructed of dense impervious stones. The use of lime mortars in the joints or at the wall surface of these buildings, in the form of pointing, sneck harling or harling, provides a route for evaporation of moisture which is not available through the stones themselves (Figure 1.5.2).

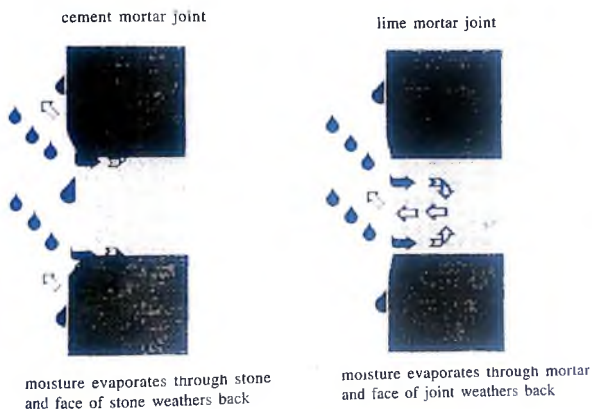


Figure 1.5.2 : Movement of moisture and associated decay at masonry joints
[Lime News, 1995].

Structural and Seasonal Movement

Lime built structures are flexible and can tolerate minute movements. Whereas the rigid material can result in cracking. This in turn can lead to water, salt solutions and gas penetration, which subsequently cause stone decay. When lime based renders are used on lime built structure, it ensures a degree of continuity which is not possible with cement renders, which frequently develop movement cracks and subsequent water penetration.

Mortar Deformation

The deformation between the rendering and the underlayer is restrained, due to the compression, tensile and shearing stresses due to the varying intensities in their tendency to move. Stresses are caused by:

- Movement in the building e.g. settling;
- Shrinkage of the mortar due to drying and hardening;
- Temperature gradient and moisture movement between the underlayer and the rendering;

If the resistance to deformation i.e the modulus of elasticity, of a mortar is low, major fluctuations in temperature and moisture will not lead to the failures. Failure rate increases reciprocally with the modulus of elasticity. For this reason the cement mortars rich in the binder are not recommended for renderings or for the joints pertaining to the natural stone masonry. Greater deformation will soon cause cement mortar to detach from the stone. Lime mortars are much more suited since they follow the deformational movements of the underlayer more readily than the cement mortars.

Other types of cements are also available today; like Slag cement, High alumina cement, Low alkali cement, etc. Recently Lime-Portland cements are also being produced.

Concluding Remarks

Portland Cements in spite of attaining early high strength are not durable in the long term. The concrete produced with portland cement as binder gets 80% of the strength after 28 days. Whereas the concrete made by lime base binder are slow hardening but have more elasticity. Lime pozzolana base binders, soil cements on the otherhand are rather fast hardening but maintains the elastic behavior. The pozzolanic reaction continues with the time thereby the strength increases and the permeability decreases. Thus the concrete becomes more durable with the oldering. Which is contrary to the Portland cement base concrete. The binding in the lime base concrete is due to the calcium carbonate formation, in the case of portland cement due to the C-S-H formation and in the case of lime-pozzolans concrete due to the alkaline alumino silicate hydrates formation. In the case of soil cements, the products of hydration are low basic hydrous calcium silicate, calcite, silica, a blend of alkali-alkaline soil, hydrous silicates, and hydrous alumino-silicates etc. These are the natural products found in the earth crust and therefore are more stable and make the concrete more durable. The circle becomes complete when the concrete made with lime and lime-pozzolanas

hardens but it is not complete in the case of portland cement. This is the reason for the instability and the movement in the concrete made with the Portland cement.

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2. STONES

Stones are used in building industry in different forms for different purposes. During the ancient period in India, these were used in making sculptures, and in making blocks for building construction. Rock cut temples were also made. These stones would be called "Building Stones." Some of the stones crushed to small pieces are used as aggregates in making the mortars and concrete. These will be called "Aggregates." Stone dust or very fine particles size can also be used in making mortars and concrete. This will be dealt under "Sand."

2.1 Building Stones

The Indian sub-continent's architecture is well documented by stone sculptures which cover a period of more than 5 thousand years. Different types of stones were used in different period which were selected subject to the job requirements. Transport being a cumbersome work, the stones used were from the vicinity of the job site. The stones used in Northern, Northeastern, Central and South Indian sculptures are summarized in the Figure 2.1 to Figure 2.3. These maps also show the domains of some of the important powers in the respective part. Geological map of India is shown in the Figure 2.4 and Figure 2.5 shows the map of India with demarcation of different states. This gives a very clear picture of the building stones used in different periods, and their present location. Figure 2.5 gives an idea of the current position as it is marked with different states. The stones used in different periods are shortly reviewed.

The oldest sculptures were found in the two cities of Indus Valley Civilization; *Mohen-jo-daro* and *Harappa*. It dates back to 3000 B.C. The Indus Valley Civilization shows the use of tertiary limestones, sandstones and mesozoic steatite for stone statuary. Vindhyan sandstone is very much used for carving the statues. From 4th century B.C to the 11th century A.D Kaimur and Bhandar sandstones remained the popular sculptural material in the greater part of Northern India. In the North-western India exclusively carved sculptures, of marbles of Kurnool Group dominate the ancient sculptures; 220 BC-200 A.D. The temples of South in the Deccan, dated 550-642 AD, are built of Bijapur sandstones. In some part of far south, sculptures made from such hard rocks as the charnockites are found. Basalt in stone art is seen in Bihar and Bengal during 700-1200 A.D. South

Karnatak sculptures used steatite between 1100-1400 A.D. In Orissa sculptures have been chiselled out of khondalites, 800-1200 A.D. From twelfth century onwards sandstones and marbles have been used in all the major monuments of Northern India whereas granites and gneisses dominate in South India. Rock cut architecture made its beginning in the third century B.C. and reached its acme in the basalt country of Ajanta in sixth century A.D.

Summary of Rocks Identified From Central and Northern Indian Sculptures

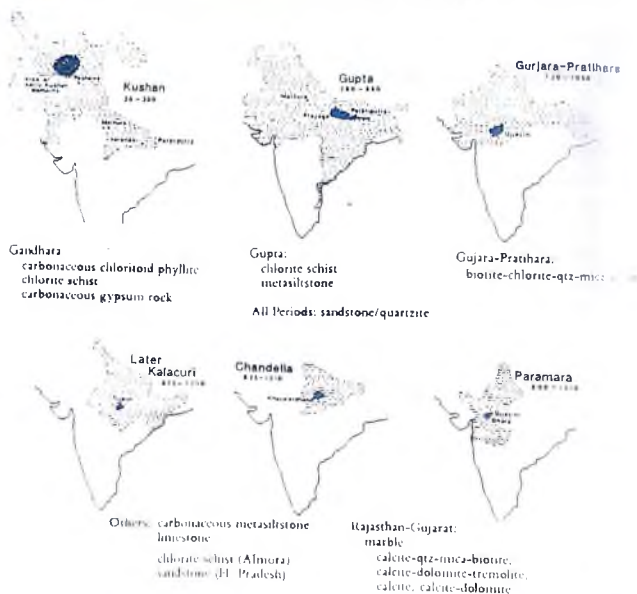


Figure 2.1 : Summary of the major types of rocks identified in sculptures from central and northern Indian sculptures; ruled areas indicate the maximum of the region controlled by the particular power and striped area indicate the central or "core" of the powers [Schwartzberg, 1978].

Summary of Rocks from Northeastern Indian Sculptures

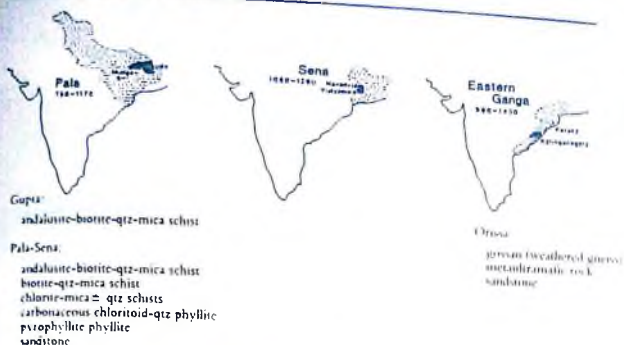


Figure 2.2 : Summary of the major rocks identified in northeastern Indian sculptures; ruled areas indicate the maximum of the region controlled by the particular power and stripped area indicate the central or "core" of the powers [Schwartzberg, 1978].

Summary of Rocks From Southern Indian Sculptures

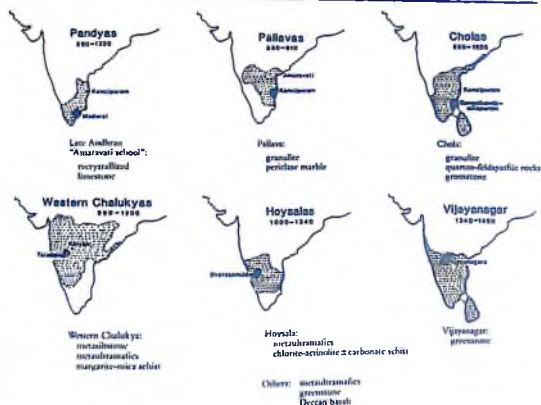


Figure 2.3 : Summary of the major rocks identified in southern Indian sculptures; ruled areas indicate the maximum of the region controlled by the particular power and stripped area indicate the central or "core" of the powers [Schwartzberg, 1978].

Geologic Map of India (Excluding Himalayan Region)

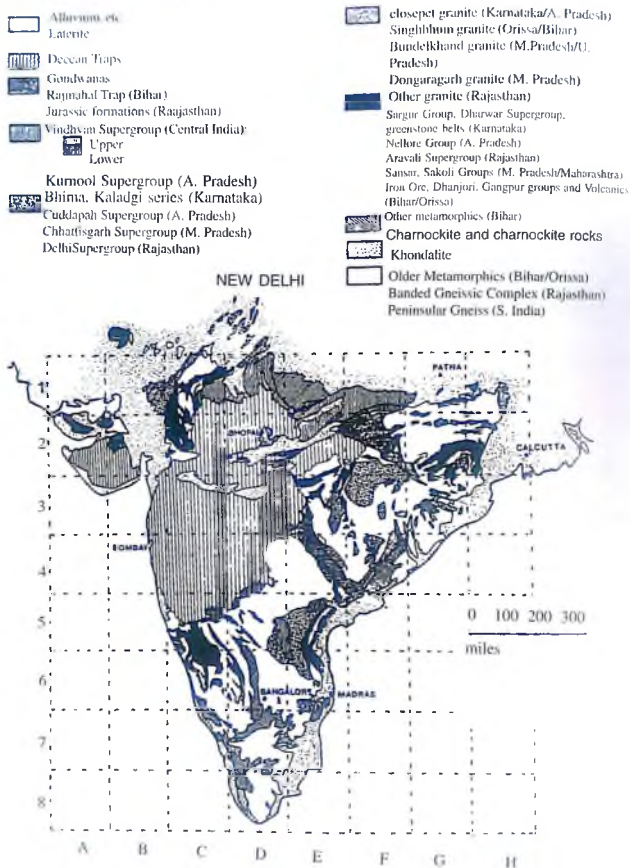


Figure 2.4. : Geological map of India showing the location of stone quarries excluding northernmost and Himalayan region [Geological Survey of India, 1962].



Figure 2.5 : Map of India showing different states.

Stones used in building construction come from different rocks. They are used in their natural form as mined. They may be cut, dressed and polished and are then termed as dimension stone. Most of the building stones are dimension stones and are used as cut or finished stone, according to the drawings supplied. Such stones are sawed or chipped into shape. Rocks are available in abundance, but only a few satisfy the requirements of building stone. The important requirements are: ease in quarrying, adequate strength, colour, hardness and workability, texture, porosity and

durability. The most important factors are the micro-cracks, texture and strength. The stones should be free from the micro-cracks. The particles in the stones should be interbonded and not sitting separately like individual round crystals. This decreases their strength and durability. Whereas interbonding increases their strength. The dimension stones should be soft enough so that it will be possible to work on them. They should have good strength, but not very high. With the increase in strength, the elasticity of the stones decreases and they become more brittle. The stones should be fine textured. These properties help in polishing them.

2.1.1 Quarrying

The rock exposure must be free from closely spaced joints, cracks, or other lines of weakness otherwise sizable sound blocks cannot be obtained. Some lines of weakness, such as well spaced bedding and joint planes, are necessary to assist in quarrying and to allow breaking to one or more flat surfaces. Otherwise the quarried rock would have to be dressed on all sides. Deep and irregular weathering is undesirable.

2.1.2 Some Common Stones and their Properties

Properties and composition of some of the most common stones used are described here:

Granite

It consists mainly of quartz, feldspar and mica. Sometimes mica is replaced by dark coloured ferrous magnesium minerals. The colour of granite depends upon the main constituent (feldspar) and the presence of dark minerals. It is also found in grey, red etc., varieties. The bulk density of granite averages 2600kg/m^3 ; its compressive strength is 100 to 300 MPa; tensile strength, 1/40 to 1/60-th of the compressive strength.

High mechanical strength, weathering and frost resistance predetermine high building qualities of granite and building materials made of it. Granite is used for facing slabs, staircases, floors, curb stones, crushed stone etc. It is also used for monuments. There are a number of temples and monuments, which were made using blocks of Pre-Cambrian granite gneiss available in Dwarahat, about 40km north of Ranikhet in Nainital district of Uttar Pradesh.

Feldspar

These are aluminosilicates, i.e., the compounds of silica with aluminum oxide and oxides of alkali metals, K_2O , Na_2O or CaO . It occurs in different

colours. Its hardness is 6, one unit less than quartz. By the character of cleavage, feldspar are divided into orthoclases and plagioclases. Orthoclases $K_2O \cdot Al_2O_3 \cdot 6SiO_2$ are straight splitting minerals; whereas plagioclases are oblique-splitting minerals. Classed with the latter are albit or sodium feldspar, $Na_2O \cdot Al_2O_3 \cdot 6SiO_2$, and anorthite, or lime feldspar $CaO \cdot Al_2O_3 \cdot 2SiO_2$. Feldspar has a compressive strength of 120 to 170 MPa, and density ranging from 2500 (orthoclases) to 2760 kg/m³ (anorthite). When exposed to aggressive environment, feldspar disintegrate more rapidly than quartz. It decomposes to alumino-silicates, in particular, to kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$), a constituent of clays, and sometimes to calcite ($CaCO_3$) [Chandra and Brouzzel, 1993].

Mica

These are hydrous alumino silicates of complex and varied composition. They are divided into two kinds; the biotite and muscovite. Biotite contains magnesium and iron oxide impurities owing to which biotite mica is opaque and dark, sometimes black. Muscovite, on the other hand is transparent since it carries none of these impurities. Mica split readily into thin elastic plates, which is evident of their perfect cleavage. The density of muscovite lies between 2760 and 3100 kg/m³, and that of biotite, between 2800 and 3200 kg/m³, their hardness being 2 to 3. Biotite is a constituent of many eruptive rocks. It weathers more readily than muscovite, which is found in eruptive and sedimentary rocks.

Diabase

It consists of plagioclase and augite and carries a certain amount of quartz and hornblende. Its bulk density averages 2800-3000 kg/m³, its compressive strength lies between 200 and 300 MPa. Its colour is dark grey. Diabase is amiable to polishing. It is used in the form of crushed or piece stone, slabs, paving blocks, and facing materials.

Basalt

It is dark, and has cryptocrystalline structure with some amount of volcanic glass. It is composed of plagioclase and augite. The density and bulk density of basalt are close to each other 2700-3300 kg/m³ and the compressive strength ranges from 100-150 MPa. High hardness and strength of basalt make them suitable for road pavings and also for the manufacture of cast stone moldings. Deccan basalt (Cretaceous-Eocene) was used for carving the sculptures at Karle 130 km south of Bombay. Basalt is found in Rajmahal

traps (Lower Jurassic) and the Rajmahal Hill at the head of Ganges delta near the border of Bihar and Bengal. The biggest rock cut caves are Ajanta caves, which have been cut into the 200m. thick Deccan trap basalt.

The various types of traps recognized in the caves are:-

1. Vesicular
 - (a) hard vesicular with or without amygdales--porphyritic/non-porphyritic.
 - (b) soft vesicular with or without amygdales--porphyritic/non-porphyritic.
2. Massive
 - (a) Coarse trap – porphyritic/non-porphyritic
 - (b) fine trap – porphyritic/non-porphyritic

Charnokites

Charnokites are very special type of stones. They are very hard and most durable stones yet they are quite amiable to fine dressing. It contains blue quartz, which imparts a cool elegance to the sculptures. These were used in the temple at Mahabalipuram near Madras.

Gypsum

Gypsum is a rock consisting of a mineral of the same name. It is used in the manufacture of an air-setting binder and also as a facing material (artificial marble) for interiors of buildings.

Dolomite

It consists mainly of the mineral dolomite $\text{CaCO}_3 \cdot \text{MgCO}_3$ with admixture of argillaceous, ferrous, siliceous and other substances. Its colour is grey, or yellowish to brownish, and is of granular structure. In properties, dolomites are close to dense limestones, and sometimes they feature mechanical properties higher than those of limestones. Dolomite is the source material for crushed stone, facing slab, and binding materials.

Limestone

Limestone consists mainly of the calcium mineral; CaCO_3 with admixtures of clay, dolomite and quartz. etc. The bulk density of limestone ranges from 1700 to 2600 kg/m³, and its compressive strength, from 10-100 MPa. The colour is white or yellowish to brownish. Limestones are used for the manufacture of crushed stone, facing slabs and architectural items. It is used for making lime, and is the major component in the production of Portland cement. There are varieties of limestones found in India. The sculptures are all carved with limestones of the Narji Formation in the Jamal Mandugu subgroup of Kurnool Group (Upper Proterozoic to Lower

Cambrian). These limestones are quarried in Palnad region. The white limestones have very attractive fine grained texture and resemble marble in appearance. Such white and light colour rocks were preferred by the sculptors. though, in the type area at Narji the limestones are deep red, chocolate, green, cream, or gray coloured. White coloured limestone have withstood weathering much better than the coloured once.

Sandstone

These are rocks composed of grains of quartz cemented by clay like, siliceous or limestone substances. The strength of sandstone is governed by the kind of binding material, the size and the shape of cemented grains. The most resistant siliceous sandstones have a compressive strength of 200 MPa and over. Siliceous and partly lime sandstones are used as crushed stone in making mortars and concrete. These are also used for facing bridge piers and building foundations, and for road surfaces because they are highly resistant to frost and abrasion. Colossal statues are generally made in India of hard and compact, fine grained Vindhyan sandstones (Upper Proterozoic to Lower Paleozoic). Besides Vindhyan Athgarh Sandstones are also found (Upper Gondwana, Lower Jurassic). There is another type of sandstone, which has been used at Mathura. It is red coloured and white spotted upper Bhandar Sandstones (Upper Vindhyan), which were quarried between Bharatpur and Fatehpur Sikri. These sandstones are quite durable and yet soft for delicate workmanship. These are highly siliceous, like the Dhandraul quartzite of Chunar, and even the matrix between the quartz grains are essentially composed of fine siliceous materials. Another type of sandstones are quarried from Panna on the banks of the river Ken. These are fine grained in texture and show various shades of buff, pink and pale yellow. The Khajuraho temples are built of these sandstones, also known as kaimur sandstone.

Marble

It is a crystalline rock, formed of limestone or dolomite. Its crystals are bound together without the intermediary of a cementing agent. The strength of marble may be as high as 300 MPa. Its hardness is relatively low, 3.0 to 3.5. It can readily be sawn and polished and is applied for facing building interiors and exteriors. However, its poor chemical resistance against sulphurous gases and atmospheric moisture makes it unsuitable for external application. The biggest use of marble was in the construction of Taj Mahal at Agra in the state of Uttar Pradesh. Pure white Makrana marble was used in Taj Mahal.

Quartzite

These are metamorphic varieties of siliceous sandstones with recrystallized quartz grain intergrown to such a degree that the cementing substance is indistinguishable. Quartzite are weather resistant, their strength is as high as 400 MPa. Applications of quartzite include facing of buildings, bridge piers. Quartzite is also found in Vindhyan area.

2.2 Aggregates

Stones are crushed to small sizes which are used as aggregates in making concrete. The size of the crushed stones can vary from 5 to 70mm. Aggregates used are according to the availability of the rocks. But most common are granite, quartz and limestone. The basic criteria of the aggregates is that they should be clean, free from the impurities of overburden; clays etc., and should not be alkali sensitive.

2.2.1 Pumice

Pumice is formed in the process of rapid cooling of magma, its mass expansion under the pressure of intensively evolving of gases. Subsequent rapid cooling of swollen lumps of magma gave rise to a glassy porous rock. The colour of pumice is grey, black and sometimes white. It consists of silica SiO_2 (upto 70%) and alumina Al_2O_3 (upto 15%). Pumice occurs in fragments 5 to 50mm across, ejected during the eruption of volcanoes. Bulk density of lump pumice is 400 to 1400 kg/m^3 , porosity 80%, compressive strength, 0.4 to 2.0 MPa, and hardness, 6. Pumice is used as aggregate for lightweight concretes as heat insulating material and as an active pozzolanic admixture to lime and cements.

2.2.2 Volcanic Tuff

During volcanic eruptions, ashes and sands are mixed with molten lava to form tuff lava. Cemented tuff lava is called volcanic tuff. Tuffs have glassy structure due to rapid cooling. A typical representative of volcanic tuff is the arctic tuff (so named after a deposit in the arctic, Armenia). The bulk density of lump tuff is 1250 to 1350 kg/m^3 , porosity 40 to 70%, compressive strength 8-19 MPa, and sometimes higher. Its colour is rose violate. Tuff is used as aggregate in making lightweight concretes and mortars, for large wall slabs and as an active pozzolanic admixture to air setting lime or cement. Excellent decorative qualities and frost resistance predetermine its wide use as a facing material for facades of buildings.

2.3 Sand

It is a loose mixture of grains of various rocks ranging in size from 0.14 to 5.0mm. By their origin, sands fall into rock, river, sea etc varieties. Typical sand consists of quartz; a mineral which resists weathering. Some grains of quartz are rounded to perfection whereas the others are sharp edged; some are smooth and shining, while others are rough due to the abrasion from the wind. Generally the particle size of the sand is sorted out by nature. An entirely pure quartz sand is rarely available. It is mixed with feldspar, mica, garnet, magnetite and other minerals.

The sand can be of different colour, which depends upon the predominating minerals present in it. For example dark colour sand is due to the presence of magnetite, ilmenite and chromite. Yellow colour sand originates from heavy non-metallic mineral such as zircon, garnet, rutile etc.

The sand used in the building construction should be coarse grained, clean, sharp and preferentially of yellow colour. It should, if possible be obtained from the local pits. River sand is generally too soft and fine. Sea sand should not be used as it contains salts like chlorides and sulphates which have deleterious effect on the mortars and concrete made from it. For using sea sand it should be thoroughly washed. A good quality sand should not contain lumps of foreign matter and contaminated with dust. If so, these are to be separated by washing before use.

Concluding Remarks

Different types of stones were used in the ancient period for making sculptures, and as blocks for making buildings. The stones used in different period varied. These were selected depending upon their availability in the nearby region and the job requirement. Care is to be taken in selection of the stones specifically looking into microcracks, texture and strength. The stones should be free from microcracks, of good strength but not very high as it will decrease the elasticity, and of fine texture. These are essential properties, which also helps in polishing the stones.

Stones are also used as aggregates after crushing. Criteria in selection of the aggregate is: Microcracks free, dust free, and should not be sensitive to the alkali.

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3. BRICKS

Bricks for building construction were of two types. The earliest use of the molded bricks was after baking them in the sun. Later, the technique was developed to burn them at high temperature. The former type of bricks was cheap and simple to make whereas the latter were complicated due to the burning process and thereby were expensive.

3.1 Sunbaked Bricks

The precise history of sunbaked bricks is not known as to when these were developed and used for the first time. However, the earliest use found is at *Dholavira*, which has emerged as a major Harappan city, remarkable for its exquisite planning, monumental structures, aesthetic architecture and wonderful water management system [Joshi and Bisht, 1994]. According to Archaeological Survey of India there were seven cultural stages. The first settlers who came to Dholavira seems to be well trained in the building techniques. They have constructed a formidable fortification (as thick as 1 meters at the base round the settlement). The houses were made of the mud bricks of standardized sizes providing the ratio 4:2:1. (Figure 3.1)

Mud bricks were also used in the construction of Indraprastha, a village of *Pandava's* (*Mahabharat*). It is clearly seen from the ruins of the village (Figure 3.2). Location of this village is at the place of Red Fort, Delhi (see Indo Aryan Architect, Part I).

Bricks are actually made from the soil and not the clay. Clay is a part of the soil, which has the bonding property. Making bricks looks very simple, but in fact it is not. There are many factors, which are to be taken into consideration for making them.

3.1.1 Selection of Soil and Brick Making Technique

The bricks should be made of specially selected soils otherwise they are not durable. For example bricks made from sandy or pebbly clay or from fine gravel, are heavy, and are not durable. It has bad bonding and are washed away in the rain. There are many kinds of clayey materials suitable for making the bricks. They may be almost pure and plastic clays (white and chalky or of red clay, products obtained by the natural decay and disintegration of igneous rock and shale, or they may be wind blown

materials with significant amount of sand and silt. These can be white and chalky clays or even red clays.

Bricks made with this type of clay are smooth, are easy to work with and have good bond. Furthermore these are not heavy.

The best materials for making the bricks are latter types, which contains up to 30% of sand and silt. The presence of sand in particular reduces the shrinkage that occurs when the plastic clays are burned. Clays are basically composed of hydrated oxides of aluminium and iron, and hydrated silicates of aluminium, but may also contain calcium carbonate, gypsum, pyrites etc. Gypsum is undesirable as it subsequently leads to the efflorescence on the face of the brickwork, and may even cause the bricks themselves to crack. The local builders have adequate knowledge and are careful in selection of the clay. Gypsum occurs in the crystal form, often in nodules, and can be felt by hand.

The soil within a foot or so from the surface is used. It is prepared with the addition of leaves, or dry straw (Chopped stems of cereals, *Bhusa*) and ample of water. It is thoroughly mixed and is left exposed for some time depending upon the weather and the time of the year. This should be kept in between to ensure thorough mixing and compaction. Which produces bricks of high durability. During this time the leaves get rotten. The juice from the leaves gives plasticity to the clay and the fibers provide reinforcement. Any nodules of gypsum are removed at the same time.

The bricks are molded in the wooden frames by casting the soil as prepared and beating it with wooden clubs (Figure 3.3). These when sufficiently dried so that they will not be deformed by movement are put over each other making open space between them like checker. This way, the air passes through them and drying takes place more uniformly. The bricks also dry faster. It is shown in the Figure 3.4. These are left for sun drying for a couple of weeks. When the bricks are dried these become stabilized, as there will be no cracks which used to come due to the shrinkage of the mud when the water evaporates. There will also not be delamination cracks, which come due to the movement of the mud during drying. These bricks are used for making the walls and the mortar used for joining them is made of the mud and the organics. When the wall is finished it is plastered with the mortar made of mud and organic. Thus it becomes a monolithic structure without cracks. The houses constructed with the sun-baked bricks are durable and stable compared to those made only with the mud.

Bricks should be made in the spring or autumn, so that they may dry uniformly. Those made in the summer are not of good quality. The bricks dry very fast on the surface due to the high temperature prevailing in the summer time while the interior of the brick is still wet. This non-uniform drying cause shrinkage in the bricks and develops cracks. The bricks loose strength. The bricks should be dried slowly and uniformly. Older are the bricks better is the service life.

When undried fresh bricks are used in a wall, the stucco covering stiffens and hardens into a permanent mass, but the bricks settle and cannot keep the same height as the stucco, the motion caused by their shrinking prevents them from adhering to it, and they are separated. Hence the stucco, no longer joined to the core of the wall, cannot stand by itself because it is too thin: it breaks off, and their settling may perhaps ruin the walls themselves.

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Figure 3.1 : North gate showing the use of mud bricks at Dholavira, Harappan City. [Joshi and Bisht, 1994].



Figure 3.2 : Ruins of Indraprastha, Delhi, cir. 1500 B.C, [India Prospective July 1996].



Figure 3.3 : Making of mud bricks, Lucknow, India [Photo, Chandra, 1999].



Figure 3.4 : *Mud bricks are cast and piled for sun drying, Lucknow, India [Photo, Chandra, 1999] .*

Sun dried earth bricks usually hand made are becoming common in rural part. The bricks are larger than the kiln fired bricks. However there is no hard and fast rule and these do not conform to any standard size. Sun dried bricks usually make stronger walls than those made only using earth.

The earliest use of mud bricks is in the construction of fortification around the settlement at *Dholavira*. It is a city of the Bronze Age, situated in the island of Khadir in the Great Rann of Kachchh in Gujarat. It was one of the largest settlements of Harrappan civilization. The houses were made of the molded mud bricks of standardized sizes providing the ratio 4:2:1.

3.2 Burnt Bricks

The history of the use of burnt bricks goes back to the Indus Valley Civilization cir. 2500 B.C. One of the evidence of the use of burnt bricks is found at Mohenjo-daro; a city of Indus Valley Civilization (cir. 2300 B.C). Most of Mohenjo-Daro was built of burnt bricks. There is massive mud filled brick embankment, and on its summit are the remains of several impressive structures, the most prominent of which is called "Great Bath" (Figure 3.5). The pool is surrounded by a paved courtyard, made of bricks and made watertight by bitumen.

Another evidence of the use of burnt bricks can be seen from the remains of a kiln excavated at Lothal, in Ahmedabad and dates back to cir. 2000 B.C. [Archaeological Survey of India]. The Lothal culture was similar to

the culture of Harappa and Mohenjo-Daro. This confirms that the builders were well versed with the technology of making and burning the bricks in large scale in that period.

3.2.1 Burning of the Bricks

The colour and the texture of the brick depends upon the iron oxide impurities in the clay and the condition of firing. The majority of clays for brick making, however, burn to a red colour when fired at between 900 to 1000 °C. in an oxidizing atmosphere. Beyond this temperature the colour often changes to darker red or purple, then grey at 1200 °C. In an reducing atmosphere in which the supply of oxygen is restricted or cut off, for example by reducing the draught through the kilns. Purple-brown or bluish bricks, often with black colours are produced. The effect of a high iron content in the clay is to produce ferric oxide in an oxidizing atmosphere, making the brick salmon pink in colour at 900 °C, and darker red or reddish brown at 1100 °C, and ferrous oxide and ferrosic oxide in a reducing atmosphere, making a bluish brick.

The bricks made as described in Section 3.1 are laid down flat on the ground to dry for a few days to dry and to get some green strength. Later they are stacked on edge for some days, after which they are burnt. The temperature of burning is about 950 °C.



Figure 3.5 : Mohenjo-Daro, the Great Bath, Harrappan culture c. 2300 to 1750 B.C. (From Craven, R.C; A Concise History of Indian Art, Vikas Publishing House, New Delhi, 1979, 13).



Figure 3.6 : Bricks are piled for burning, Lucknow, [Photo Chandra, 1999].



Figure 3.7 : Burning of the Bricks, Lucknow, [Photo, Chandra, 1999].



Figure 3.8 : A brick kiln excavated at Lothal, Ahemdabad, India; c. 2500 B.C.[ASI].



Figure 3.9 : Fuel used for burning the bricks, Lucknow, [Photo, Chandra, 1999].



Figure 3.10 : *Round down draft kiln for burning the bricks, Lucknow [Photo, Chandra 1999].*

Bricks are burnt either in heaps or clamps “*Open Bhatta*” or in specially constructed kilns “Round Down Draft Kilns”.

Open Bhatta

In clamp-burning a foundation consisting of a layer or two of burnt brick is formed as a level site to protect the clamp from damp rising from the ground beneath. Channels are arranged in the foundation in such a way as to form a number of fire holes or flues running the length and breadth of the clamp. These flues are filled with fuel. The green bricks with more fuel between them are stacked and spaced so that the fire can penetrate through the whole mass. The bricks are seen piled in the Figure 3.6. Burnt bricks and mud is laid over the top of the stack to protect it from the weather and heat loss. The clamp is set on fire and allowed to burn. It can take couple of days. One such arrangement is seen in Figure 3.7. In the ancient period large kilns or clamps must have been used to produce vast number of bricks

required for building the shelter houses for the settlers during the Indus valley civilization. The remains of one such kiln is shown in the Figure 3.8. It was excavated at Lothal in the Ahmedabad, India and dates back to about 2000 B.C.

The fuel used is the dry grass, wood, and cakes made out of cow-dung, which are dried and coal. Some of the fuels stocked on the burning site are shown in the Figure 3.9. Production of large quantity of bricks requires a large amount of fuel. In case of scarcity of the fuel the bricks were made with the addition of straw which serves as a fuel for burning the bricks. In many cases it was sufficient for burning the bricks or required very little extra fuel. There was an added advantage by mixing straw, the bricks became lighter, as they have created empty space after burning.

The temperature attained in the kiln was related to the amount of fuel used e.g. number of cakes or the amount of wood etc. The fuel was calculated in such a way so that the bricks are properly burnt. There were no thermometers for measuring the temperature. It was estimated by the colour of the flame. It was rather accurate. After burning of the fuel, a glow which lasted for a long period as the kiln is covered very tightly with mud. Thus the heat is available for long time which keeps the kiln hot. This is known as soaking period. It means that the temperature remains constant for certain period of time. During this period the sintering process and the reaction at high temperature continues. The kiln is opened after a few days, When the temperature automatically goes down. Thus the bricks slowly cool down and are not exposed to the sudden temperature change, thermal shock, which will occur if the kiln is opened when still warm. In this situation the bricks will crack due to the unstabilized ceramic bond and not proper weathering.

Round Down Draft Kiln

More advanced way of burning the bricks was to burn the bricks in a special kiln "Round Down Draft Kiln". This is used for mass production of the bricks. It is shown photographically in the Figure 3.10. In down draft kiln there are interconnected chambers. The bricks are stacked in these Chambers. The principle is that during burning a draft is created due to the convection currents by the temperature variation. This draft "air" from the burning chamber passes through the outlets to the next chamber and the bricks are preheated. When this chamber goes under heating the burning chamber goes under cooling. Thus the draft passes to the next chamber from the burning chamber all the time. It is a continuous process. Because

of the draft movement. such kilns are named "Down Draft Kilns". This process is productive and saves a lot of energy as it is used in preheating.

Tunnel Kiln

Now a days the bricks for making the houses in the urban areas are produced in the automatic factories, where the bricks are molded in the brick press, dried and burnt in the tunnel kilns with complete temperature control. The kilns are fired with furnace oil. The bricks are loaded on the specially made trolley which moves on the rails. These are pushed inside the tunnel kiln. The tunnel kiln has three zones; preheating zone, firing zone, and cooling zone. The movement of trolleys is automatically controlled so that they stay in different zones for desired time. The trolleys are pushed out after burning. These are much better in quality; warpage is very low as these are not handled manually, and because of this and the complete control of temperature in the kiln are well burnt and are sound e.g the bricks have less cracks. The rejection is less. The productivity increases and the bricks become cheaper inspite of the expensive Production cost.

3.2.2 Bricks Inspection

The bricks thus produced are inspected. The inspection is done for the size control "warpage" and the soundness of the bricks e.g. testing of the cracks inside the bricks. Mostly the inspection is done visually or by the sound resonance, which is also performed basing upon the experience of the able builder. The brick is knocked by an iron piece, it produces sound. If the sound produced is not clean and clear the brick has cracks. The warpage is tested completely visually. The bricks, which do not pass these tests, are unfit to be used for building construction and are rejected.

These rejected bricks are crushed and used for making the aggregates for making masonry or pulverized for making brick dust known as "*Sarkhi*" which is used as a pozzolanic material.

3.2.3 Brick Size

The bricks made were of different sizes. There were small bricks and big bricks. small bricks were called "*Lakhauri*". These were about three and quarter of an inch thick, and about four by six inches in length and breadth. The word Lakhauri itself comes from the word lakh. It means lakhs (10 lakh = 1 million) of bricks for construction. There were also larger and heavier bricks about two inches thick, which were known as *Pan Patta* or according to P.C. Mukherji or "*Ilmasi*" after Ilmas Ali Khan, the Deputy Governor of Oudh during the time of Saadat Ali Khan, who reputedly used

these thicker bricks in his own buildings. There are also instances where curved bricks and triangular bricks were made. The triangular bricks were used for making the core of the statues. However there was no specific standard about the size. Smaller bricks, lakhauri owing to the great number used gave tremendous strength to the structure. The other advantage is that they can be used both with the "Pan Patta" bricks and also by themselves to form remarkably fine details even before the stucco has been applied. Similarly, the big bricks because of the bigger size work as load bearing blocks. Some of the bricks are shown in the Figures 3.11 and 3.12.



Figure 3.11 : Big brick from the old construction at Lucknow, [Photo Chandra 1997].



Figure 3.12 : Small bricks "Lakhauri" in old construction at Lucknow [Photo Chandra 1997].

Concluding Remarks

Earliest use of bricks found in India is in Dholavira about 3000 B.C. The bricks used were sun baked as well as burnt. The bricks were made in different sizes from the clay, which was selected very carefully. These bricks were sun dried before burning in the kilns. The burning was done using fuel which was a measure for the ultimate temperature of the kiln and the time of burning. Strict inspection was done to insure good contact between the bricks. Bricks thus made were of very high quality and there was no problem of alkali leaching as is often seen. It is attributed mainly due to the excess amount of alkali in the clay used for making the bricks, which gets dissolved and leaches out producing white precipitation on the brick surface.

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4. NATURAL POLYMERS

4.1 Introduction

Natural Polymers are the organic materials found in nature. These will be named NP. These are mostly natural and agricultural products. These constitute of many components, which have a natural balance. This makes them stable in a very wide range of atmospheric conditions. Whereas synthetic polymers are man made in factories and are stable only in specified conditions. One of the living example of this is apple juice and apples. If left on the kitchen table juice gets fermented but not the apples. Apples are protected by the skin and other components, which has a natural balance and give them longer life whereas juice having no protection gets fermented the next day.

NP have been used in building construction much before Christ. That some of the ancient structures are in good shape even today speaks about their durability. The ancient builders had empirical knowledge without adequate scientific background. To-day the things are reversed in many cases. People are highly educated and there are ways and means of testing the material, but there is shortage of time. We are living in a commercialized world where quick solution to the problems are looked for, without looking for the long time durability aspects.

In ancient period the builders use to say

"Go use this, it will work". What to-days builders say *"Go try this, it may work"*. So they are safeguarding themselves by saying try and may. This happens when one is not confident which comes from lack of sufficient practical knowledge.

This being their living bread the ancient builders did not write about it. The knowledge passed on through the hereditary "Father to the son, son to son." This is one of the reason why the knowledge about the things, which were practiced successfully in the ancient period are successively disappearing. However, in the rural areas it is still practiced but in scattered form.

In the ancient period the communication and transportation was difficult. The materials were used according to their local availability. Being the natural products their composition which depends upon the soil and the climate vary from place to place. This may be one of the reason why there were no strict rules or standards to be followed.

4.2 The Oldest Natural Polymer, Bitumen

One of the oldest natural polymer used was bitumen, an amorph, semi-solid, or viscous mixture of complex hydrocarbons derived from petroleum deposits. Bitumen occurs naturally in rock asphalt and in lake asphalt. It occurs as a fluid mixture of bitumen, very fine siliceous silt, clay, and some insoluble organic matter. Another source is the natural seepages through the veins in the earth, which had adsorbed wind blown sand and other matter to form a kind of asphalt. Such deposits occur in many parts of the middle east from Egypt to Pakistan. It is this asphalt that is assumed to have been used by the local people in the early civilization for bonding brickwork, for damp-proofing, for lining of drains, water basins, baths etc.

The use of asphalt as a water proofing material spread upto Indus valley, 25 miles south of Larkana, in Sind, Pakistan, and its performance was appreciated. The Indus valley civilization's two cities are said to have been Mohenjo-daro and Harappa (3250 to 2750 B.C.). Most of Mohenjo-daro was built of kiln fired bricks. At Mohenjo-daro, there is a massive mud filled brick embankment, and on its summit are the remains of several impressive structures, the most prominent of which is called the Great Bath (Chapter 10, Figure 10.15) [Craven, 1979]. The pool is surrounded by a paved courtyard, made of bricks and made watertight by bitumen [Marshall, 1926].

Mud houses, sun baked bricks and the lime mortars used for joining the kiln fired bricks do not have long time durability. For this reason natural polymers were used which enhance the durability properties when exposed to the adverse atmospheric conditions. These were mixed in the plasters applied on the walls or in the mortars for joining the bricks. As already mentioned, there was not adequate documentation of the NP's. There are some excerpts in the mythological books like *Mansoullas* [Shamasastri, 1976] for the natural polymers and in *Chitrasutra of Vishnu Dharmotra* [Sivarammurthy, 1978] the method of their application. According to the *Mansoullas*, the plasters to be applied on the walls consisted of natural polymers like, *Katha*, *linsers*

(green and black gram), molasses, boiled bananas, sugar, oils, eggs, milk products etc. The composition and the process of making lime washes, plasters and mortars are elucidated in the Chapters 5, 6 and 7. Here only the nature and the characteristic properties of natural polymers are described.

4.3 Function of Natural Polymers

Natural Polymers were used to improve the properties of plasters, mortars and clays both in the fresh as well as in hardened state. By their addition the durability properties were significantly enhanced. Besides this, these were also used as insecticides against the attack of ants, termites etc. It was difficult to collect the information about all the natural organic products used in the ancient period. Characteristic properties of some of them are described.

The natural polymers used basically were from cereals, milk products, vegetables, fruits, oils and fats, liners (pulses), sugar compounds, eggs, flowers: *Saf, Mahua, Besharam* etc, and some other agro-products like cactus milk, *Deodar* milk, cashew nut milk, *Har-Bahera* etc. A general description of some of these natural organic product is given first featuring their specific characteristic. Later, their chemical interactions with the cementitious material are elaborated. In the end some specific natural polymers used are defined with their botanical name (latin name).

4.3.1 Cereals

Carbohydrates; 80% of dry matter of cereals is carbohydrate. The two carbohydrates present are crude fibers and soluble carbohydrate. The fiber constituents are cellulose, hemicellulose and pentosans. Of the soluble carbohydrate, starch is the most important carbohydrate in all cereals. Small quantities of dextrin and sugars are also present.

Protein: Cereals contain 6 to 12% protein. The types of protein present in cereals are albumins, globulins, prolamine (gliadin) and glutelin. The proportion of these proteins differ in different cereals. The gliadin and glutelin are known as gluten proteins. When water is added to the flour, gliadin combines with glutelin and gluten is formed. The gluten has unique elasticity and flow properties.

Wheat

The distribution of carbohydrate in wheat is as follows:

Starch	95.8
Sugar	1.5
Cellulose	0.3
Hemicellulose	2.4

Proportion of different proteins in wheat grain as a percentage of the total protein are:

Albumin	5-10
Globulin	5-10
Protamine	40-50
Glutelin	40-50

Wheat proteins are rich in glutamic acid and low in tryptophan. Glutamic and aspartic acid are present in the amide form as glutamine and asparagine. The high concentration of amide is important in determining the characteristic of the gluten. Effect of wheat protein structure on molecular association and properties is shown in the Figure 4.1a, and a model for the structure of gluten is shown in the Figure 4.1b.

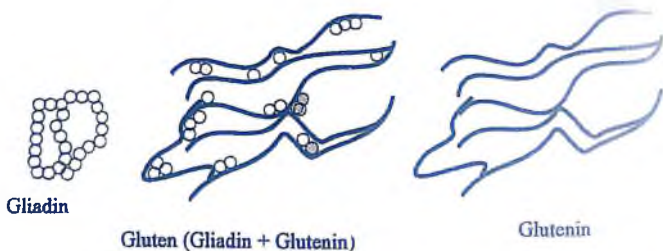


Figure 4.1a : Effect of wheat protein structure on molecular association and properties.

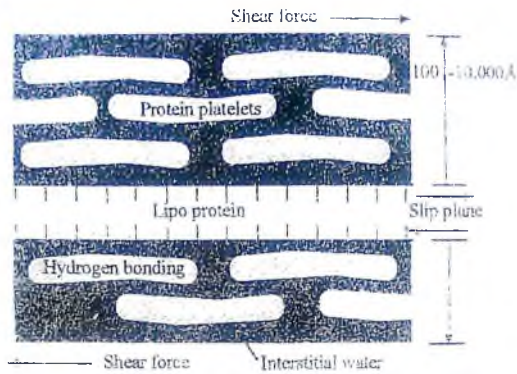


Figure 4.1b : *A model for the structure of gluten, [Paulin C. Paul and Helen H. Palmer, Food Theory and Applications, John Wiley and Sons, Inc, 1972].*

When flour is mixed with water, protein platelets of coiled polypeptide chains are formed and that these platelets are linked perhaps by hydrogen bonds to form continuous sheets. Within the platelet, it seems probable that the hydrophilic side chains of the protein are oriented towards the water and the hydrophobic side chains are oriented towards the air phase, pores. The lipo- protein, which is believed to be attached to the platelets by hydrogen bonds or salt like linkages, makes the gluten elastic by permitting the platelets to slip on one another and returns to their original position.

The wet gluten is a cohesive, elastic mass that expands greatly when heated. Glutenin or glutelin is the protein, which gives toughness and rubberiness to gluten. Gliadin gives elasticity.

Two different types of chains may be distinguished in a starch. The linear termed amylose and the branched termed amylopectin. Amylose is soluble in water. One type of starch differs from another both in the length of amylose and amylopectin chains and in the proportion of each type of starch chains. The gelling property of a starch depends upon the amylose content and a high amylopectin levels lowers the ability of the starch to form satisfactory gel.

Calcium salts tend to increase the elasticity of the gluten.

Starch: Starch granules do not dissolve readily in cold water. But as the temperature increases, the hydrogen bonding decreases for both the starch-starch bonds and water-water bonds and the size of the particles diminishes. Increasing water molecules begin to penetrate freely between the starch molecules when their kinetic energy becomes great enough to overcome the attraction between the starch molecules. Two starch molecules, which were originally bound together are now separated by a water layer in between. The sticking together of granules is the result of molecules from adjacent granules becoming attracted and enmeshed in one another. The changes brought about by hot water on starch are irreversible.

Starches containing relatively large amounts of amyloses such as corn starch form firmer gels than starches with a somewhat lower concentration of amylose, such as tapioca.

Many starch molecules are disrupted during the process of gelatinization as the starch granules swell. Some of the molecules of amylose, the linear starch fraction leach out from the granule. Two or more of these chains may form a juncture point, creating a new bond, which gradually leads to more bonds and more extensively ordered regions. Bonding with amylose molecules begins immediately after cooking. Amylopectin, the branched fraction, usually remains inside the swollen granule where it more slowly forms new bonds between branches in a process of recrystallization. Bonds formed between the branches of the bushy amylopectin molecules are weak and have little practical effect on the rigidity of the starch paste, however, bonds between the long chain amylose molecules are relatively strong and form readily. This bonding produces a three dimensional structure that results in the development of a gel with the amylose molecules forming a network that holds water in its meshes. The rigidity of the starch mixture is increased.

Two of the most important factors that influence the rate of retrogradation are temperature, size and shape of the starch molecules.

As starch thickened, mixtures continue to stand after gel formation is complete. The process of retrogradation may continue to produce changes as additional bonds are formed between the straight chain amylose molecules. The amylose molecules associate more closely together. Some of these molecules aggregate in a particular area in an organized crystalline manner. As the amylose molecules pull together more tightly, the gel network shrinks and water is pushed out of the gel. The process of weeping called syneresis results from the increased molecular association as the starch mixture ages ultimately an ordered crystalline structure develops.

Uses

Wheat flour consists of two parts: i) Fine part, and ii) Coarse part. Fine part is called *Maida* and the coarse part is known as *Chokra*. Fine part contains gluten and the coarse part contains fibers. When mixed in the mortars, plasters or concrete, shrinkage is controlled as it reduces the plasticity index. It also helps in fast drying and provides better bond.

4.3.2 Rice

Rice is of different varieties, and so their composition varies widely. Mainly these constitutes of carbohydrates and proteins.

Carbohydrates: The major carbohydrate of rice is starch which is 72-75%. The amylose content of starch varies according to the grain type. The longer grain and superior types containing upto 17% amylose, while some coarse type are completely devoid of it. *Glutinous rice* consists almost entirely of amylopectin. Rice also contains some free sugars like glucose, sucrose, dextrin, fructose and raffinose. The fibers of rice is the hemicellulose made up of pentoses, arabinose and xylose.

Protein: the protein content of rice is 7%. gluten, which is also known as oryzenin is the principle protein of rice. Rice also contains small quantities of albumin, globulin and protamine. The rice proteins are more rich in arginine compared to the other cereal proteins.

Uses

Glutinous rice has been cooked till it becomes a paste, it has then been mixed with lime to make lime mortar. When the starch is warm, the hydrogen bond weakens and the interaction with lime becomes easier. It makes a very strong bond, and the complex formed is very durable.

This mortar has been used amongst other places for joining the stones in the great China Wall. It is very adhesive and sticks very well. X-ray diffraction analyses did not show any peaks of either calcium hydroxide or calcium carbonate [Chandra, 1990]. It implies that some chemical interaction has taken place and calcium complex is formed which has amorph or cryptocrystalline form. Owing to this there was no peak in the x-ray diffraction analyses.

4.3.3 Pulses (Linsers)

Pulses are the edible fruits or seeds of pod bearing plants belonging to the family of leguminous. Mainly three varieties of pulses have been used in the building materials: Moong, Black gram and Soya bean.

Pulses contains proteins, carbohydrates, lipids and minerals. Mainly they contain globulins. Albumins can also be seen in pulses. Pulses are rich in lysine.

Composition of moong and black gram is given in the Table 4.1.

Table 4.1 : Composition of Some Pulses

	<i>Protein g</i>	<i>Fat g</i>	<i>Carbo- hydrate g</i>	<i>Calcium mg</i>	<i>Iron mg</i>	<i>B- Carotene mg</i>
Black gram	24.0	1.4	59.6	154	3.8	38
Moong	24	1.3	56.7	124	4.4	94
Soyabean	43.2	19.5	20.9	240	10.4	426

Carbohydrates: Pulses contain 55 to 60% starch. Soluble sugars, fibers and unavailable carbohydrates are also present. The unavailable sugars in pulses include substantial levels of oligo saccharides of the raffinose family.

Lipids: Pulses contain 1.5% lipids on the moisture free basis. They contain high amounts of polyunsaturated fatty acids.

Calcium and magnesium: Large amounts of insoluble calcium and magnesium pectates are formed in the middle lamella of the cell walls when the seed is high in calcium and magnesium. When they come in contact with hard water, which contains chlorides and sulfates of calcium and magnesium salts. They appear to react with pectic substances and phytates and harden the cellulose.

Guargum: It is a gel forming galactomanan-polysaccharide derived from the cluster bean has the ability to bind bile acids.

Uses

It is used as chemical admixture in the building material. It enhances cohesiveness, workability and decreases water absorption.

Black gram, Urad ki daal: It contains 24% proteins, 60.3% carbohydrate and 1.4 % fat with traces of calcium, iron, magnesium, sodium, potassium, sulphur and phosphorous. Proteins are built of amino acids arranged in

long chains. The following amino acids were present; leucine, isoleucine, valine, methionine, alanine, histidine, tryptophane, phenylalanine, lysine, glutamic acid, and aspartic acid. Carbohydrate mostly consists of polysaccharides such as starch. Starch consists of two discrete kinds of molecules amylopectin and amylose. The former has a structure similar to that of glycogen but less highly branched, whereas the latter is linear.

These interact and make complexes by cross linking, decreasing their solubility and increasing their stability. The adsorption is probably in the internal as well as external layers, which makes it chemically resistant.

It works as air entraining agent, introduces cohesiveness, and improves adhesion. It enhances resistance to water absorption of mortars and concrete.

It is said that in Poland, a newly built silos was leaking. It became a big problem, as it costed very much money. But the solution came from an old mason not from a highly qualified engineer. He impregnated the silos with water mixed with flour and was left for drying. It never leaked again. Proteins from the flour hydrolysed and made complexes with the calcium hydroxide, which filled the pores, cracks and the capillaries. These complexes are hydrophobic in nature [Chandra and Ohama, 1994].

Animal Waste

Stabilizing properties: It improves adhesion, binding, plasticity and durability.

Forms: Fresh or weathered, dung, shorn, manure.

The action of these material is linked to their fibrous content but chemical reactions also occur in earth mixes bringing about the formation of a cementitious gel. Dung can also be used alone as a protective coating on earth walls.

Addition of cow dung controls the shrinkage as by their mixing the plasticity index is reduced. These also help in fast drying and provides better bond. Apart from this, it also acts as antiseptic and insecticide.

Urine

Stabilizing properties: It improves dispersion of fines during mixing, reduces shrinkage, promotes drying and increases hardness.

Forms: Fresh or stale, horse or human.

Blood

The major protein in blood is hemoglobin, which is responsible for the transport of oxygen and carbon dioxide in the blood. It contains four polypeptide chains (each with its bound heme group) of two types, designated α and β in normal adult mammalian hemoglobin. The hemoglobin present in the human-being is reduced form deoxyhemoglobin and oxy-nated form, oxy-hemoglobin in the horse.

The structure of human oxyhemoglobin H containing four β chains is found to resemble reduced hemoglobin and to be unaffected by deoxygenation. The structure of horse oxyhemoglobin contains four polypeptide chains which assumes a configuration very close to that of sperm of whale myoglobin. These four subunits are arranged in a tetrahedral manner forming a compact spheroidal molecule.

Sir Hugh Plat [1653] described a stucco that was of great use in Italy “Temper ox blood and fine clay together, it will become a very strong binding substance. Blood from different sources differs. Bostock and Riley [1855] gave an explanation of why ox blood is preferred over the other

“The blood of the bull coagulates and hardens the most speedily of all...Blood is the richest quality in the ass and poorest in the man. The blood of the wild boar stag, roe buck and oxen of all kinds does not coagulate.”.

Stabilizing properties: Water proofing, increase hardness and gives a shiny surface when polished.

Forms: Fresh or dried ox blood is usually used

Uses

It is probably used in the buildings of extra importance. The main protein is hemoglobin.

4.3.4 Milk and Milk Products

Milk is a complex mixture of lipids, proteins and many other organic compounds and inorganic salts dissolved or dispersed in water. The most variable components of milk is fat followed by protein.

Factors affecting the composition of the milk

1. The composition varies according to the species.
2. Variation in the composition of milk occur with the breed of the cow. Some breeds of cow gives milk which is always higher in fat and protein than that of others.
3. The time of the year has an effect on the composition of milk. This may be indirect since the diet of the herd and the amount of green pasture consumed varies with the time of year.
4. Composition of the milk varies with the time of the day. The evening milk tends to contain more fat and less water than the morning milk.
5. It varies with the portion of milking. Milk, which is first removed from the udder contains a smaller amount of fat than that removed in the final phase of milking.
6. The diet of the cow has a very marked effect on the quality of milk produced but only a limited effect on the composition.
7. Composition also varies with the **time** of the lactational period initially the animal secretes colostrum. It is lower in water, sugar and fat and higher in casein, albumin, globulin. The most striking difference between normal milk and colostrum is the globulin, which often reaches 12% to 13% in the colostrum. Threonine level in milk protein is 15% higher at the end of lactational period than 60 days after the birth of the calf. The milk which is secreted after the delivery of the calf contains large fat globules. There is considerable decrease in size until about the second month. Towards the end of the lactation period the milk produced by a cow often has a salty taste due to less amount of lactose and more amount of chloride. The most remarkable difference between colostrum and milk is the extremely high content of homeoglobulin of the former.
8. Fat content increase slightly from the first to the second or third lactation period and then remains the same.
9. When the cow is excessively fat, it provides liberal amount of milk.
10. The longer the interval between milking greater the quantity of milk and lower the fat content.
11. Within the limits of the same breed and with uniform environmental conditions, a considerable range of individual variations occur especially in the fat percentage.

Milk fat: Milk is true emulsion of oil-in-water. Fat globules are visible under a microscope. Each globule of fat is surrounded by a thin layer which is composed of a lipid-protein complex and a small amount of carbohydrate. The lipid portion includes both phospholipid and tri-glycerides.

Fat globules vary widely in size from 2-10 μm (micro meters) and in number 3×10^6 per ml. During the first part of the lactation period the fat globules are relatively large and as lactation progresses the granules become larger. The larger fat granules come to the surface of milk more quickly due to low specific gravity. In cheese making, if the fat globules are large, they will move up quickly before the coagulated milk could check their movement and as a result the loss of milk fat in whey is somewhat large. In milk transport, large fat globules churn more readily after being transported some distance and show the formation of butter granules on the surface.

Milk fat is a mixture of several glyceride. They contain about 64 fatty acids ranging from 4-26 carbon atoms. Milk contains considerable amounts of short chain fatty acids, which give the characteristic flavor and off flavor. Due to their low melting point they produce solids of consistency to butter. Saturated fatty acid account for the butyric and capric acid 62% and unsaturated 37%. Of the unsaturated fatty acids 3.8 constitute polyunsaturated fatty acids.

Other lipid material present in milk are phospholipid, sterols, free fatty acids, carotenoids and fat soluble vitamins. Carotenes are responsible for the yellow color of milk fat.

Milk proteins

Casein: Casein constitutes 80% of the total nitrogen in milk. It is precipitated on the acidification of milk to pH 4.6 at 20°C. The remaining whey protein constitutes lactoglobulin and lactalbumin. Milk protein contains proteoses, peptones and milk enzymes.

Casein is classified as a phosphoprotein because of the phosphoric acid that is contained in its molecular structure. At the normal acidity of fresh milk (about pH 6.6) casein is largely combined through the phosphoric acid part of its structure with calcium caseinate. Hence, casein occurs in milk as a colloidal protein calcium phosphate complex. In milk α -casein 66%, β -casein 29%, γ -casein 5%. δ -Casein, which is part of the α -casein plays an important role in stabilizing the tiny caseinate particles in a colloidal dispersion.

Casein is a protein with serine phosphate as specific functional groups. Under basic conditions it dissociates forming anionic phosphate groups.

Casein shows strong surface active behavior and can be classified as an anionic surfactant [Morr, 1979].

Casein

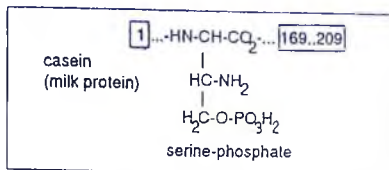


Figure 4.2 : Structure of Casein.

Casein is also a glycoprotein. The calcium content of whole casein is about 8.2%. Carbohydrates are present to the extent of 5.7%. Glutamic acid is the predominant one in casein. Proline, aspartic, leucine, lysine and valine are also present. Casein is a good source of essential amino acids. The structural composition of Casein is shown in Figure 4.2.

Casein can act as a liquefier and it increases water vapor permeability.

Whey protein: Whey protein are made of α -lactoglobulin and β -lactoglobulin, serum, albumin, the immune globulins, enzymes and proteose-peptones, α -lactoglobulin accounts for about 50% of the total whey proteins. These are not precipitated by acid or serum, they can be coagulated by heat. Whey also contains small amounts of lactoferins and serum transferrin.

Uses

Addition of milk products in the plaster, mortar and concrete improves binding, water proofing, and thereby the durability properties. Milk and sauer milk are also used as aid for polishing.

Forms: Buttermilk, skimmed milk, casein and cream cheese

These additives generally occur in lime based mixes and rely on the formation of calcium caseinate which is hard and relatively insoluble.

Milk sugar: The chief carbohydrate present in milk is lactose or milk sugar is a disaccharide, although trace amounts of glucose, galactose and other

sugars are present. Lactose gives on hydrolysis glucose and galactose. When milk is heated lactose reacts with protein and develops brown color. The development of brown color is due to non-enzymatic browning. It is called Maillard reaction. Reducing sugar reacts with the amino acid lysine and brown color develops.

Salts: Chlorides, phosphates, citrates, sulfates and bicarbonates of sodium, potassium, calcium and magnesium are present. These salts influence the condition of and stability of proteins, especially the casein fraction. In addition to this, milk contains trace elements like copper, Zinc, aluminium, molybdenum and iodine.

Acids: When milk is heated its acidity decreases at first owing to the release of dissolved carbon dioxide and then increases because hydrogen ions are liberated when calcium and phosphate forms insoluble compounds. The balance between these opposing factors prevents large changes of pH during heating.

At pH 6.6 casein is present largely as calcium caseinate. When acidity is increased either by the addition of acid or by natural souring, acid removes calcium and phosphate from calcium caseinate changing to casein. Casein coagulates when the pH has been reduced to about 4.6 and is least soluble at its isoelectric point pH 4.6. When the pH reaches about 4.6, the colloiddally dispersed casein particles become unstable. They adhere together and form a coagulum or curd. This probably occurs because the usual negative charge on the casein particles, which causes them to repel each other and remain apart is neutralized by acidic hydrogen ions. The precipitated casein can be rendered soluble by additional acid or alkali either of which shifts the pH away from the iso-electric point.

Two stages in the clotting of milk

1. Calcium phosphocaseinate	Rennin →	Calcium sensitive phosphocaseinate
2. Calcium sensitive calcium phosphocaseinate	+Ca ⁺⁺ →	calcium caseinate (gel)

4.3.5 Eggs

Eggs consists of four parts; shell, shell membrane, egg white and egg yolk (Figure 4.3).

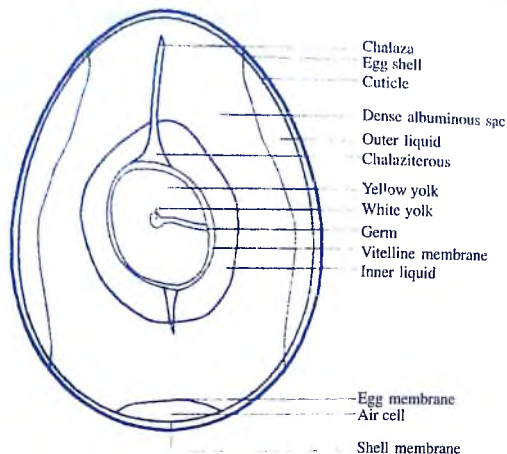


Figure 4. 3 : The parts of an Egg.

Shell: It forms the protective covering of the inner contents of the egg along with the two membranes. The matrix fibers have significant influence on shell strength and they pass through calcite or calcium carbonate instead of surrounding it. The matrixes are made up of protein polysaccharide complexes. An egg shell is brittle and easily breaks.

It is porous and contains thousands of small holes, which allow gases to pass in and out of the egg for the developing embryo. The small holes are covered with a thin layer of gelatinous material mucoprotein called cuticle or bloom. The cuticles seal off the pores of the shell to some extent and helps avoid an excessive evaporation from the inner content of the egg. It also restricts the entry of micro-organisms into the egg and thus protects the inner contents from various infections. This cuticle is soluble in water and easily removed by washing which results in hastening the denaturization of egg quality.

Shell membranes: Within the shell are inner and outer membrane that also protect the quality of the egg. Both the membranes are porous and composed of fibers. The outer membrane which is thicker (48 μ m) than the inner one (22 μ m) is firmly attached to the shell. The outer membrane has six layers of fibers, where as, the inner one has three layers. The inner membrane is attached to the outer and the two membranes are loosely attached to one place usually at the broad end of the egg. The membranes are composed of protein and polysaccharide.

The eggs contain little or no air cells when they are laid. After being laid because of the lower temperature of the outer surroundings of the egg than when it was in the hens body, there is contraction of the inner contents of the egg. This results in air being drawn into the shell resulting in a small air cell formation between the shell membranes usually at the large end of the egg.

It is primarily calcium carbonate deposited in an organic matrix. The composition of egg is given in Table 4.2.

Table 4.2 : Percent composition of Egg Shell

<i>Components</i>	<i>Percent</i>
Calcium carbonate	93.07
Magnesium carbonate	1.39
Phosphorous pentaoxide	0.76
Organic matter (matrix protein and polysaccharide)	4.15

Egg white: The white of the egg consists of three layers, two areas of thin white encompassing one area of thick white.

Egg yolk: It is enclosed in a sac called the vitelline membrane. Immediately adjacent to the vitelline membrane, a thin membrane that surrounds the egg yolk, is chalaziferous or inner layer of firm white.

The composition of egg white and yellow differ considerably (Table 4.3). The lipid content of albumin is negligible when compared to yolk. A very small amount of glucose is present in the egg white.

Table 4.3 : Percent Composition of Egg White and Yolk

<i>Nutrients</i>	<i>Egg white</i>	<i>Egg yolk</i>
Water	88.0	48.0
Protein	11.0	17.5
Fat	0.2	32.5
Minerals	0.8	2.0

The chief constituent of egg white besides water are proteins.

Ovalbumin: This constitutes 55% of the protein of egg white. This is a phospho-glyco protein and is composed of three components, A1, A2 and A3 which differ only in phosphorous content. The relative proportion of A1, A2, A3, component is 35:12:3. The carbohydrate component of albumin are mannose and glycoamine in the ratio of 5:3. Ovalbumin in solution is readily denatured simply by mechanical agitation. At pH 9 and at 62°C only 3-5% of ovalbumin is denatured.

Conalbumin: This constitutes 13% protein of the egg albumin. It consists of two forms neither of which contains phosphorous nor sulphur. Conalbumin is more easily heat coagulated and less susceptible to surface denaturation than ovalbumin. The protein easily binds metallic ions such as iron copper, aluminium, zinc forming heat stable compounds.

Ovomucoid: It is glycoprotein. This constitutes about 10% of the egg white proteins. It exist in three forms and all of which are trypsin inhibitors. It is resistant to heat denaturation in acid media but is readily denatured in alkali solution.

Ovomucin: The protein is responsible for the jelly like character of egg white and the thickness of the albumin. It contains 2% of the egg white. Its content in the thick layers of albumin is about 4 times more than in thin layers. It is insoluble in water but soluble in dilute salt solution. Purified ovomucin in solution is resistant to heat denaturalization. It is a very large molecule with filamentous or fiber like nature.

Lysozyme: 3.5% of the egg white protein is lysozyme. This is an enzyme capable of lysing or dissolving the cell of wall of bacteria. It is heat sensitive.

Avidin: This protein is 0.05% of the egg white protein. It is comprised of 3 components, A, B and C. It binds biotin and makes the vitamin unavailable. Avidin is denatured by heat

Ovoglobulin: It is a protein consisting of two components G1 and G2, and both are excellent foaming agent.

Ovoinhibitor: 0.1% of egg protein is made up of ovoinhibitor. It is another protein capable of inhibiting trypsin and chymotrypsin.

Egg white foams

Egg white foam is a colloid consisting of bubbles of air surrounded by albumin that has undergone some denaturization on the liquid air surface. This denaturization which is due to the drying and stretching of the albumin during beating makes one of the albumin insoluble thus stiffening and stabilizing the foam. During denaturization the protein molecules unfold and their polypeptide chains lie with their long axis parallel to the surface. Over beating incorporates too much air stretching the albumin so that it becomes thin and less elastic.

The ease with which the egg white can be whipped to a fine foam with small cell is attributed to the presence of ovomucin, ovoglobulin, and conalbumin.

Sir Hugh Plat [1653], gave a recipe of stucco whiere egg white replaced arabic gum.

4.3.6 Sugar Compounds

Molasses

It is the residue that remains after sucrose crystals have been removed from the concentrated juices of sugar cane or beetroot. It contains not more than 25% water and not more than 5% mineral ash.

After the first crystallization of sucrose, the molasses is high in sugar and light in color. After the final process, a dark and bitter product with a relatively high mineral content, called black strap molasses remains.

Jaggery

Jaggery is mainly obtained from sugar cane though it can also be prepared from palm, date palm and coco-nut. For making jaggery cane is crushed and coarse suspended impurities from the juice are removed by straining and then the juice is boiled. Chemical clarificants are used to flocculate colloids present in the juice. After clarification the cane juice is boiled vigorously to 115°- 175°C with constant stirring and then concentrated into thick almost semi solid mass, which on cooling solidifies into jaggery.

Good quality jaggery has a light color, good flavor, hardness, crystalline structure and good keeping quality. It contains 65% to 85% sucrose, 10-15% invert sugar and 2.5% ash. Jaggery does not crystallize because of the invert sugar and it is very much preferred when noncrystalline candies are prepared. It is specially used when it is used as binder in the preparation of chikki and puffed rice balls.

Uses

It is a very sticky sugar cane product. It helps very much in increasing the adhesion. Many organics have been used in pairs or in combination of others which compensates the negative aspects and thus completes each others fallacies. But if used alone, can cause insect problems. This problem is overcome by using poisonous juices like from cactus, fermented milk and straw etc.

Jaggery being a non-crystalline product is preferred to the crystalline sugar because of its easy reactivity.

Corn syrup

It contains 75% carbohydrate and 25% water. Acid and high temperatures are applied to hydrolyse corn starch. The carbohydrate of the resulting product comprises from 10 to 36% glucose and from 9 to 20% maltose, the remainder consisting of higher sugars and dextrin.

Sap - Nira

The fresh sap of palms, called "sweet *Toddy* or *Nira* contains about 12% of sucrose and unless suitably treated, fermentation into "*toddy*" starts almost immediately after collection. *Toddy* is a cheap alcoholic drink, generally used in the suburbs.

Freshly drawn up sap of different palms usually preserved by the addition of calcium hydroxide. *Nira* contains 84.7% moisture and 14% sugar.

Coconut water

The water of the unripe coconut is a refreshing drink and has the advantage of being sterile. Analyses of the coconut water gives the following values; water 95.5%, protein 0.1%, mineral matter 0.4%, carbohydrates, 4.0 parts per 100 ms. The nut water contains calcium, 29; phosphorous, 37; iron, 0.05; and potassium, 312 mg per 100 gm. The principal mineral constituent is thus potassium. The water is rich in ascorbic acid, which ranges from 2.2 to 3.7 mg per 100 ml. The water from green nuts, with soft pulp, contains still higher concentration of ascorbic acid, which interacts with calcium hydroxide and makes complexes.

Uses

It is used in polishing the buidlings

4.3.7 Oils and Fats

Vegetable oils are produced from different substances. They vary in their composition depending upon the source from where these are produced. Composition of some of the oils is given in the Table 4.4 and the fatty acid composition is given in the Table 4.5

Table 4.4 : Composition of Some Oils

Almond	Rich in fat and protein- globulin, B.V is low
Cashew-nuts	Protein-20%, arginine-10.3%, histidine-1.8%, lysine-3.3%, PUF
Mustard	Oil-40%, protein-20%
Soyabean	Protein 43.2%, oil 19.5%
Charoli (Sara)	Oil 51.8%, protein-21.6%, starch-12.1%, sugar-5.0%
Sesame	Protein 20%, A-globulin rich in calcium
Sunflower	oil 40% high in protein
Walnut	Protein-50%, oil -65%

Table 4.5 : Percent Fatty Acid Composition of Commonly Used Oils

<i>Oil</i>	<i>Saturated</i>	<i>Mono-unsaturated</i>	<i>Poly-unsaturated</i>
Coconut	91	8	1
Cotton seed	34	26	40
Groundnut	20	54	26
Mustard	6	73	21
Niger	12	35	56
Palm	80	13	7
Safflower	11	13	76
Sesame	14	46	40
Soybean	15	25	60
Sunflower	8	34	58

When fats contain a relatively high proportion of saturated fatty acids such as palmitic and stearic acids, they have relatively high melting points and are usually solid at room temperature. When fats contain a relatively high proportion of unsaturated fatty acids such as the mono-unsaturated oleic acid and poly-unsaturated linoleic acid, they have relatively low melting points and are oils at room temperature. Linoleic acid of some of the edible oils is given in the Table 4.6.

Table 4.6 : Linoleic Acid Content of Some Edible Oils

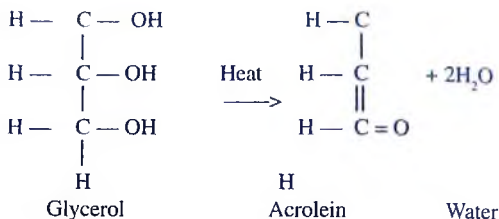
<i>Edible oil</i>	<i>Linoleic acid content</i>
Safflower	77.1
Sunflower oil	61.4
Cotton seed oil	58.0
Soya bean oil	50.2
Sesame oil	45.9
Corn oil	43.0
Rice bran oil	36.0
Ground nut oil	35.0

As the number of carbon atoms in the fatty acids increases, thus making longer chain fatty acids, the melting point also increases. Butyric acid with four carbon atoms melts at lower temperature than does stearic acid with eighteen carbon atoms. Both of these fatty acids are saturated. Butter contains a relatively short chain fatty acids and melts at a lower temperature than does beef fat or hydrogenated shortenings, which contain more long chain fatty acids.

Plasticity: Most fats that appear to be solid at room temperature actually contain both solid fat crystals and liquid oil. The liquid part is held in a network of small crystals. Because of this unique combination of liquid and solid the fat can be molded or pressed **into** various shapes without breaking. This property of fat is called plasticity.

Pyrolysis (thermal breakdown)

The action of heating the oil causes a break down in its molecular structure. When fat begins to smoke, its chemical breakdown begins and free fatty acids and acrolein are formed from glycerol.



Hog's Lard

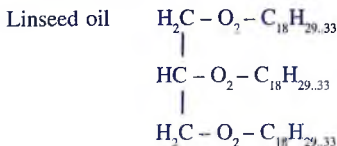
Fat from the abdomen of pig. To make lard, fatty tissues of the hog are chopped into small pieces and heated, with or without the addition of water to remove fat from the cells, a so called rendering process. The quality of lard depends upon the method of heating. The arrangement of some of the fatty acids within the fat molecules may be changed by a process known as esterification.

Emulsifiers for the fat are egg yolk, whole egg, gelatin, pectin, starch paste, casein, albumin, and fine powders like paprika, mustard.

Uses

Water-proofing, improves adhesion and cohesion and durability properties.

Linseed oil: It is yellow-green color oil and is made by pressing the linseeds. It has high content of linoleic acid. It has many unsaturated fatty acids with 18 carbon atoms.



Forms: Linseed oil (raw and cooked), tallow, lanolin

Heat may be needed to break down the solid fats and is available during lime slaking. Linseed oil can be combined in cold earth mixes and is easily absorbed by dry porous materials.

Maize/Corn oil: It is yellow color oil and is made by pressing corns. It contains several unsaturated fatty acids.

Mustard oil; It is light vegetable oil of yellow color and is made by pressing white mustard seeds. It contains iso-thiocyanate ($R-N=C=S$), which gives specific sharp smell, characteristic of mustard oil.

In *Land and Building News* [Anon, 1856] is listed a Turkish recipe that used 100 lb picked kilned lime, 10 qt. linseed oil, and 1 to 2 oz. cotton. Linseed oil was also used by Collepari et al [1972] for water-proofing the concrete, durability properties thereby were significantly improved. Chandra and Xu [1995], have tested different types of oils, namely, maize oil, linseed oil, mustard oil in mortar. It was seen that their addition plasticity and the water penetration resistance of concrete significantly increased.

4.3.8 Spices

Asafoetida, It is an oleo gum resin exuded from the rhizome or root of *Ferula asafoetida*. The odor components consists of a ferulic ester and sulphur containing volatile oil. It is available in the market mixed with starch. It is used as anti-microbiological agent.

Sea-Weeds

It is the sodium salt of the amino acid, glutamic acid, mono-sodium glutamate. It is an extract from the Japanese sea weed

Uses

Sea weed addition improves binding, waterproofing and gelling agent.

Forms: Tangle (kelp) is often mentioned in old recipe but other species are used in earth mixes in Europe. Vitruvius describes mortar recipes containing lime and dried seaweed.

4.3.9 Vegetables

Vegetables are plants or part of the plant. These parts vary in their water, protein, vitamin, mineral and carbohydrate content. The botanical classification is given in the Table 4.7. Apart from this these also contain pectanes and pigments.

Pigments

The colors of many vegetables result from the various pigments occur in plastid- specialized body lying in the protoplasm of the cell. Sometimes the water soluble pigments are dissolved in the vacuoles and not generally distributed through out the cell. The chief pigments of vegetables and fruits can be classified as fat soluble and water soluble.

Fat soluble pigments

Chlorophyll: The green pigments of leaves and stem are usually held close to the cell wall in small bodies called chloroplast along with some carotenes and xanthophylls: two chlorophylls are isolated "a" and "b".

Table 4.7 : Botanical Classification of Vegetables

Groups	Examples
Roots	Carrot, beet root, reddish, turnip, colocasia
Tubers	Potatoes, sweet potatoes, tapioca
Bulb	Onion, garlic, leaks
leaves	Cabbage, lettuce, spinach, amaranth, fenugreek leaves, coriander leaves, mint leaves
Flowers	Plantain flower, cauliflower, neem flower, broccoli
Fruits	Tomatoes, brinjal, lady's finger, pumpkin, cucumber, gourds (ash gourds, bottle gourd, ridge gourd), capsicum, drumstick, plantain
Legumes (pods & seeds)	Peas, beans, chowli, broad beans, french beans, double beans, bengal gram
Stems	Plantain stem, ginger, amaranth stem, celery stem
Seed sprouts	Green gram, bengal gram, soybean, sprouts
Fungi	Mushrooms

Chlorophyll, a, is intense blue green color and chlorophyll, b, is yellow green color. They occur in plants in the ratio of 3a : 1b. Chlorophyll, a, is present in the florets of blue green broccoli and chlorophyll, b, is present in stalks. Chlorophylls are mostly insoluble in water and dominant in unripe fruits. Other pigments present are masked by dominating chlorophyll. The pigment is present in green leafy vegetables, capsicum, beans, peas and chilies.

Carotenoids: These are group of yellow, orange, red fat soluble pigments widely distributed in nature. In green leaves they occur in chloroplast. In plants carotenoids are present as alpha-carotene, beta-carotene, gamma-carotene, xanthophylls and cryptoxanthin. Type of carotenoid pigments present in food is given in Table 4.8

Table 4.8 : Pigmenting Compounds of Some Vegetables

Vegetables	Pigments
Yellow corn	Cryptoxanthene
Tomatoes	Lycopene, beta-carotene
Red capsicum	Cryptoxanthin, capsorubin, beta-carotene, violanthin, capxanthin
Green Capsicum	Lutein, beta-carotene, violaxanthin, neoxanthin
Carrots	Beta carotene, alpha-carotene, gama-carotene, lycopene, xanthophyll

Water soluble pigments: There are a group of chemically related pigments and are divided into anthocyanins and anthoxanthins, Anthocyanins are highly water soluble pigments that range in color from red to purple. The anthoxanthins are colorless, or white.

Anthocyanins: These are contained in the vacuole of plant cells where their solubility in water makes them disperse freely. Cherries, red apples, various berries, red and blue grapes, pomegranates, and currants achieve their color appeal because of predominance of anthocyanins. The red color in the skin of radishes, sweet potatoes and the leaves of red cabbage is due to anthocyanins too.

Anthocyanidins: These are anthocyanins without sugar in their structure. They are pelargonidin (red), cyanidin (reddish blue) and delphinidin (Blue)

Organic acids

Vegetables contain a number of organic acids, metabolic products of the cells. Formic, succinic, citric, acetic, malic, fumaric, tartaric, and benzoic acids are present in fruits and vegetables. The concentration of acid is lower in vegetables than in fruits. Tomatoes and vegetables with the concentration of acid have a pH ranging from 4 to 4.6. Fruits like lemon, mango green, tamarind (tartaric acid), gooseberries, raw citrus and grape fruits have low pH. Most of the vegetables have pH 5.0 to 5.6. Potatoes and peas have pH 6.1 to 6.3, more neutral taste.

Cellulose and Pectic Compounds

Sodium bicarbonate disintegrates the cellulose and produces a soft texture. Acid tends to produce firmness of texture. This is the reason why its addition makes the cereals and pulses soft in shorter time.

Effect of calcium salts

Calcium chloride or the saturated solution of calcium hydroxide has the effect of making the vegetable tissues more firm forming insoluble calcium salts with pectic compounds. The resulting calcium pectinates or pectates precipitate and add rigidity to the structure.

Small amount of calcium acetate or other calcium salt prevents the mushiness by blocking the breakdown of the hemicellulose.

Effect of sodium bicarbonate

When sodium bi-carbonate reacts with chlorophyll the phytyl and methyl groups are displaced and bright green water soluble chlorophyllin is formed. It give mushy structure due to the breakdown of hemicellulose in the cell walls.

Flavonoids

These are a group of chemically related pigments and are divided into anthocyanins and anthoxanthins.

Effect of pH

As the pH changes, the color of anthocyanin changes as follows:

pH	3	7	8	10	12	14
Colors	crimson	Purple	greyish purple	grey	greenish grey	bright green

The acidity of the cell in which these compounds are formed causes the molecules to have a positive charge on the oxygen atom. This form, which is common at a pH of 3.0 or less, maintains or shifts the hue towards red. However, the positively charged oxygen form called an oxonium, is altered to the quinone form as the pH is increased towards a weak acid or even neutral solution. The quinone form has a violet color. In an alkaline media still another change takes place as a salt of the violet compound, called a color base, is made. The alkaline salt of the color base has distinctly blue color.

Betacyanins undergo color changes parallel to anthocyanins. An acidic medium promotes a reddish color, whereas a neutral or somewhat alkaline pH brings out the blue color.

Anthoxanthins are white if the acid such as lime juice or vinegar is added. These turn to yellow or orange in the presence of the alkali.

4.3.10 Fruits

Fruits are products of flowers and they are the ripened ovary or ovaries of a plant together with adjacent tissues. Fruits are fleshy or pulpy in character often juicy and usually sweet with fragrant, aromatic flavors.

Fruits are very poor source of protein and fat. Avocado is the exception containing 28% fat.

Fruits contain 75 to 90% water. Dissolved in water, the bulk of which is found in the vacuoles, are soluble compounds like sugar, salts, organic acids and water soluble pigments. Substances unable to dissolve in water are colloiddally dispersed in it.

Cellulose and Pectin Compounds

The body of the fruit is made up of cellulose, which forms the walls of the plant cells and in which large amounts of water is held.

Apart from cellulose and hemicellulose, pectic compounds are found in cell walls and between the cells. They act as a cementing substance and bind cells together. Pectic substances include protopectin, the insoluble parent molecule, pectinic acid or pectitin and pectic acid. The change in solubility of the pectic substances occur because of ripening or the influence of heat. This makes the tissues disintegrate. Acids make the structure more firm whereas alkalis tend to disintegrate the fibers.

Flavor Constituents

Volatile flavor compounds are esters, aldehydes, acids, alcohols, ketones and ethers.

Banana contains alcohol and esters including amyl acetate, isomethyl acetate, butyl butyrate and amyl butyrate.

Pectic substances

Pectic substances are a group name for the various derivatives of galacturonic acid polymers contained in the primary cell wall and the middle lamella of fruits and vegetables.

Protopectin is the water insoluble form of pectic substances occurring in immature fruits and to a less extent in vegetables. This pectic substances contribute significantly to the firm texture of unripe fruits. It is methylated very long polymer of galacturonic acid.

As then fruit ripens, some demethylation and hydrolysis occur along the protopectin molecules. When only a limited amount of degradation has occurred, the pectic substances are termed pectins. As additional

demethylation occurs and hydrolyses continues. pectic acids from low methoxyl pectins are formed. These are valued for their ability to form gel structure with very little sugar.

The transition takes place from a methylated water insoluble polymer (protopectin) to a shorter, methylated compound capable of dispersing easily in water (pectin).

As the degradation of pectinic acid continues, the molecules gradually become shorter and lose all of their methoxyl groups. These shorter polymers of galacturonic acid are designated as pectic acid. Pectic acid is found in over ripen, very soft fruits and vegetables. This type of pectic substance has lost gel forming ability characteristic of the longer methoxyl esters of the galacturonic acid polymers.

Demethylation of protopectin occurs gradually during ripening of fruits and vegetables. The enzymes responsible for the splitting off of the methoxyl groups collectively are known as pectinesterases. Their action to remove methoxyl groups from the structures of the pectins and pectinic acids causes some loss of the gel forming properties of the compounds and a distinct softening in the structure of the fresh fruit itself. The pectinesterases are designated by such names as pectin methoxylases, pectases and pectin demethoxylases. Enzymes observed to increase during ripening of fruits include lipase, pectic enzymes, invertase, chlorophyllase and peroxidase.

4.4 Insecticidal Natural Polymers

There are some plants and substances from animal world which have been used in the ancient period in India to eradicate insects and micro-organisms [Gupta and Haider, 1995].

Acorus calamus Linn (Sweet flag) Vernacular-Bacha

Medicinal value of this plant is well recognized right from the ancient times. In *Charakya Samhita*, which is traditionally considered to be a supplement of *Vedas*, multifarious type of uses are prescribed. However, the insecticidal property of the plant has been envisaged recently.

The plant is a semi-aquatic permeable herb with a very (very branched) rhizome. Since the rhizome of this plant is also said to have insecticidal virtue, it is being used as such for the protection of textiles and documents. Pulverized dry roots of the plant filled in small cloth bags are kept in the cupboard bearing manuscripts and textiles either for display or in storage. Dry rhizome has a strong odor and contains 1.5 to 3.5% of yellow aromatic volatile oil and a bitter principle named acorin. According to

Chopra [1965] "The rhizomes of *Acorus calmus* (sweet flag) are the source of an essential oil known for medicinal and insecticidal properties.

Artemisia nilagirica (Indian Wormwood) vernacular- Nagadamani

A traditionally known plant bearing an essential oil whose sweet aroma and its insect repellent action was exploited in many ways by the natives of Assam and its adjoining area. Recent investigations has shown that the essential oil extracted from the plant *Artemisia nilagirica* could be used as an insecticide as well as repellent for various insects which usually attack the museums and historical buildings. The price of extracting the oil from this plant is less expensive than the synthetic insecticides and is less toxic.

Azadirachta indica (Margosa) - Neem or Nimb

Margosa tree bearing wonderful medical properties is known from remote antiquity. Almost every part of this tree viz. wood, bark, leaves, flowers and fruits is used. There is an age old belief that *Neem* timber can ward off attacks of insects like powder-post beetle and termites. It is for this reason that in many regions, villagers use neem wood for making door frames. The heart of the *Neem* contain a material provisionally called nematode. Some scientist hold the view that nematode is a phenolic ketone and it is due to the presence of phenolic compound that the neem wood can keep the insect pests at bay.

"Bark of neem tree contains nimbin (0.04%), nimbinin (0.001%), nimbidin (0.04%), Nimbosterol (0.03%), Volatile oil (0.02%) and 6% tannin. *Neem* bark was chemically examined and it was found to be a source of bitter alkaloid to which name was given as margosine. Its leaves contain a little bit less amount of the bitter constituent "Margosine or Nimbin" than its bark, but this bitter substance of neem leaves is more readily soluble in water than that of bark. *Neem* oil which has got astounding pesticidal and therapeutic virtues-is extracted by pressing its seeds.

Cinnamomum camphora (Camphor) Vernacular; Kapur

There are many varieties of *Cinnamomum Camphora* trees, many of them provide camphor. Of course the basic raw material to produce camphor is turpentine.

Chrysanthemum cinerariifolium (Pyrethrum)

95% of the insecticidal activity of Pyrethrum lies in the flowers and comes from a mixture of six chemical constituents, pyrethrin I, pyrethrin II, cinerin I, Cinerin II, Jasmolin I, Jasmolin II, collectively called pyrethrum. It acts as a contact poison with a rapid knock down effect on a wide range of insect species.

Pyrethrum is one of the safest insecticides known. It has very low mammalian toxicity and is rapidly metabolized if accidentally swallowed.

Mentha arvensis (Mint)- Pudina

It is used as kitchen herb. The oil derived from *M. Arvenis* by steam distillation is the basic raw material required for natural menthol manufacture. In its natural form the mint plant leaves are used to repel cockroaches, ants etc.

Nicotiana (Tobacco)-Tambaku

Nicotine occurs in at least 15 species. It is prepared commercially by the steam distillation of tobacco waste in the presence of alkali and concentration of the distillate. The concentrate is marketed as such or it is further treated to obtain nicotine sulphate. Sprays and dusts containing free nicotine or nicotine sulphate are employed as contact insecticides.

Nigella sativa Linn (Black Cumin) Vernacular-Kalazira or Mungrela

It is extensively cultivated in India. Its seeds contain 0.5 to 1.4 % of essential oil and a saponin. The seeds have a strong, pungent aromatic taste. In India, it is also used as preservative to sweet condiments. It is a common practice to scatter the seeds between folds of linen or woollen clothes to prevent them from being eaten by insects. Often, the seeds are mixed with camphor powder and sprinkled between the folds of textiles. One of the living example of its use as insect repellent is Ram Nagar Museum at Varanasi where the brocaded silken clothes of the ancestors of Kashi Naresh have been protected from the insects.

Saussurea lappa C.B, Clark (Costus) Vernacular- Kuth or kust

The root of the plant contains the alkaloid Saussurine. The roots are used for medicinal purpose and to protect the woolen fabrics from the insects. Unlike naphthalene it does not tarnish the gold embroidery. Costus is a herb. Its roots yield an essential oil up to 1% on steam distillation and resenoids when extracted with solvents.

Suntalum album (Sandal wood) Vernacular-*Chandan*

Sandal wood posses an insect, uvenile hormone actively disturbing the physiological process of the developing insect larvae. Sandal wood dust is commonly used as insect repellent. In many traditional houses the dust is kept in the cupboards, or in the morning sandal wood is burnt and the smoke spreads in the whole house. According to the mythology, it was used to clean the air inside the house.

Vitex negundo (Nirgandi)

It is a deciduous shrub commonly found through out India. After being dried in the sun, the leaves of the shrub are inserted between the bundles of palm leaves manuscripts. This helps in keeping the insects away from the materials to be preserved.

Vetiver zizanoides linn-*Khus*

It is densely tufted perennial grass with branching roots which yield the fragrant vetiver or khus oil. In India it is found everywhere. Major constituents of Vetiver oil are Khosol, Khusinol, Khusitone, Cadenene and Laevojuneol etc. Besides, other uses the roots and oil both are kept inward for perfuming clothes and as insect repellent.

Peacock Feathers

While the feathers are attached to the peacock it leaves an enormatic accretion which spreads through out the feathers. When the feathers are detached the residual aroma acts as insect repellent. In the ancient period very often the peacock feathers have been used as book mark. It has been found that it saves the book from the insects.

Gurcuma domestica, Turmeric-Haldi

Turmeric is generally used in northern India for making food. It is eatable insecticide. Its active principle is the alkaloid content which has repellent property for insects.

4.5 Interaction of Natural Polymers with Soil

The Natural Polymers are chemically very diverse, and they include: cationic species, such as proteins and amino compounds, neutral compounds, for example, the polyalcohols and polysaccharides, and the anionic polymers, represented by poly (acrylic acid). The molecular weight of the polymer can range from a few thousand to several millions. The functionality may be high, as in poly (vinyl alcohol), or as low as a single group attached to a macromolecule.

Although the nature of the bond between the organic compound and mineral surface does not vary for different minerals, the extent of adsorption varies markedly. Some minerals, such as the montmorillonite group, can adsorb organic compounds between the macromolecular silicate sheets (the internal surface), whilst the kaolinite group only presents an external surface for reaction. Some organic macromolecules adsorb over the whole mineral surface. Various types of interaction are possible. The bonding can be by hydrogen-bonding, as in the case of poly(alcohols), polysaccharides, non-ionic surfactants, or by cation exchange, as in protonated amines, proteins, and carbonium compounds. Organic macromolecules with negatively charged groups, such as poly (acrylates) or polysaccharides with acid groups, are not attracted to clay surfaces, which are usually negatively charged. However, there are positively charged sites at the edges of clay particles where polyions become attached, often forming bridges with divalent metal ions such as calcium.

4.5.1 Soil Minerals

There are three main groups of soil minerals; kaolines, montmorillonites and illites. The kaoline group includes nacrite, dickite, halloyite and kaolinite, the latter two being of most interest. All these minerals are composite sheets base on layers of $[\text{Al}_2(\text{OH})_4]^{2n}_n$, macroions in which Al^{3+} occupies tetrahedral coordination and $[\text{Si}_2\text{O}_5]^{2n-n}_n$ macroions, in which the Si^{4+} occupies a tetrahedral coordination.

The kaolinite structure is formed by combination of one each of these ionic layers to form a 1:1 sheet structure, the thickness of which is 7Å. These 1:1 minerals are characterized by low cation exchange capacity and surface area and are electrically neutral or bear a small negative charge.

Micas, chlorite, pyrophyllite, talc, vermiculite and montmorillonite contain $[\text{Al}_2(\text{OH})_4]^{2+}$ layer sandwiched between two $[\text{Si}_2\text{O}_5]^{2-}$ layers. The thickness of the 2:1 sheet is around 9.6\AA and is often negatively charged due to isomorphous substitution of Si^{4+} by Al^{3+} or Al^{3+} by Mg^{2+} . In mica the charge balancing ion is K^+ and the sheet thickness is 10\AA . The charge balancing is $[(\text{Mg}_2\text{Al})(\text{OH})_6]^+$ in the chlorites and hydrated Mg^{2+} in vermiculite and the sheet thickness is about 14\AA in both cases.

4.6 Mechanisms of Organoclay Complex Formation

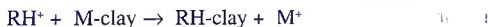
Several mechanisms are available but there is no general understanding and their classification is confused in the literature. The most complete classification is however given by Mortland [1970]. This is adopted here.

4.6.1 Cationic

Adsorption or formation of organic cations at the clay surface can take place in three ways; i) Ion-exchange, ii) Protonation at the clay surface, and iii) Hemi-salt formation.

Ion-exchange

The ion exchange process can be represented by the general equation:



The equilibrium is indirectly affected by pH since the concentration of RH^+ , $[\text{RH}^+]$, is related to pH by the equation:

$$\text{pK}_a = \text{pH} + \log \frac{[\text{RH}^+]}{R}$$

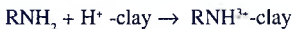
When $\text{pK}_a - \text{pH}$ is 1 to 2, $[\text{RH}^+] > R$ and the exchange is favored. The pH, however, may be affected by the metal ions liberated from the clay, e.g. Mg^{2+} and Al^{3+} . This type of adsorption may be influenced by other intermolecular forces e.g. hydrogen bonding, ion-dipole interactions and dispersion forces. The importance of these secondary forces depends on the molecular size and configuration of the molecule and the nature of its functional group.

Protonation of Organic Molecules at the Clay Surface

Organic molecules can be protonated in three ways at the clay surface:

- by exchange at a cation site
- by reaction with the hydration layer of metal cations on an exchange site, and
- by exchange with another cationic species at the clay surface.

The first example is represented by the reaction



The reaction depends on the acidity of the clay and is characterized by a high enthalpy and degree of irreversibility.

The second example can be represented by the reaction:



Brindley [1971] observed that water can be increasingly dissociated by a factor of 10^3 to 10^7 due to high field strength of the cation. The sequence of this polarizing effect is $\text{Al} > \text{Mg} > \text{Ca} > \text{Li} > \text{Na} > \text{K}$.

The third example is by exchange with a cation at the surface,



The position of the equilibrium is a function of the acid constants and concentrations of A and R.

Hemi-salt formation

Sometimes cationic molecules are adsorbed in excess of the exchange capacity of the clay, when it may be postulated that two molecules compete equally for a single proton to form a symmetrical hydrogen bond of the type B-H^+ . An example of such a base is pyridine.

4.6.2 Anionic

Anions are not expected to adsorb on negatively charged clay surfaces because of coulombic force of repulsion. However benzoic acid has been observed to adsorb on montmorillonite, in the dry, to form benzoate ions. The reaction can be represented by:



The amount of benzoate formed depends on the nature of M and is greatest with polyvalent cations. Polyanions adsorb from aqueous solution onto clays. Adsorption occurs at the edge of the clay crystal and often involves metal cation bridging,

e.g. $R^{n-} - M^{2+}$ -clay.

4.6.3 Ion Dipole and Co-ordination

This mechanism describes the interaction between polar molecules and metal cations adsorbed on the clay surface. These cations can attract molecules with dipolar groups and those with vacant d-orbitals can form co-ordination complexes [Mortland. 1970]

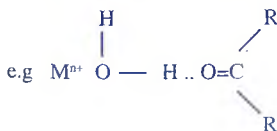
The adsorption of non-ionic but polar, molecules, such as alcohols, was considered, traditionally, to occur via hydrogen bonding between these molecules and polar groups of the clay surface, such as Si-O and Si-OH. Whilst hydrogen may play a subsidiary role, it is evident from the infra-red spectroscopic studies that polar molecules can be adsorbed in association with metal ions at the clay surface. The interaction can involve the d-orbitals, as for example ethylamine-Cu clay. The general process can be represented as:



Molecules that are adsorbed in this way include: ethanol, ethylene glycol, ammonia, ketones, urea, amides, pyridine, nitrobenzene, and amino acids. Water plays an important role here because of its strong interaction with clay; few complexes of this type form from aqueous suspensions.

4.6.4 Hydrogen Bonding

With small molecules at least three possible situations can arise. A polar organic molecule can be adsorbed by interacting with the primary hydration sphere of a metal cation. When an organic cation is adsorbed another polar molecule can interact by hydrogen bonding:



When the neutral organic molecule is RNH_2 , this case corresponds to hemi-salt formation, discussed earlier in the Section 4.6.1. Finally, there is infrared spectroscopic evidence showing that molecules can interact with the oxygen atoms and hydroxyl groups of the clay minerals.

4.6.5 Covalent Bonding

Organic molecules, including polymers, can combine with clays by covalent bonding. This can be done using silylating agents. Alternatively, organic compounds bond the clay surface under the influence of high energy radiation

The amount of polymer adsorbed by a mineral depends on the molecular weight of the polymer and the concentration of the mineral suspension. In suspensions of low concentration, adsorption increases as the molecular weight of the polymer increases, because portions of the polymer molecules adsorbed at the edge of the mineral protrude into the solution and are hydrogen bonded to other polymer molecules. Because of their longer length, polymers of higher molecular weight are more effective at binding to other polymer molecules. As the concentration of a clay suspension is increased, the average distance between clay particles is diminished and interparticle bridges can be formed, either by a polymer molecule adsorbing across two clay particles, or by the interaction of polymer molecules adsorbed onto different clay particles. The formation of interparticle bridges sterically hinders the adsorption of other polymer molecules, especially on the internal surface of the mineral, and so reduces adsorption. As higher molecular weight, polymer molecules are the most effective bridge formers, the amount of polymer adsorbed in concentrated clay suspensions is reduced as the molecular weight of the polymer is increased.

4.7 Complexes with Polyalcohol

Polyalcohols adsorb on clay minerals as a coating over the surface. This adsorption is on the internal surface of the mineral and is limited by the size of the cation adsorbed on the mineral. If the polymer is added to a suspension of clay mineral, which is above a certain suspension concentration, polymer chains can form links between individual particles and build up flocs. Most of the work reported in literature concern polyvinyl alcohol (PVA) and salts of montmorillonite. Emerson found that soil crumbs produced by treatment of soil with PVA were more stable than those formed using sodium alginate or vinyl acetate-maleic anhydride copolymer. These have interlamellar structure [Emerson 1956]. Hydrogen bonds were

considered to be responsible for the stability of the complex. An ionic mechanism was precluded as the structural stability did not depend on pH and the complex was even stable to wards sodium hydroxide solution.

Similar results have been reported by Greenland [1963] on the studies made on montmorillonite using suspensions in 88% hydrolyzed poly(vinyl acetate). PVAc and by Emerson and Raupach [1964] using completely hydrolyzed PVAc. They have further reported that the order of adding PVA and salt to form flocs is important and a mechanism has been proposed by Emerson and Raupach [1964]. It is illustrated in the Figure 4.4. If PVA is first added a network of loose polymer-clay bonds is formed (Figure 4.4a); then the addition of an electrolyte has the effect of causing the clay particles to move closer together and align, thus increasing the viscosity and floc strength (Figure 4.4b). On drying, the suspension flocs are fully formed with complete linkage (Figure 4.4c). Alternatively, if the salt is first added to suspension, the clay particles move together and align (Figure 4.4d). On addition of PVA, smaller flocs form, viscosity increases less and fewer clay-polymer bonds form than in the previous case (Figure 4.4e). The structure formed by drying these flocs will be weaker than before and swells to a greater degree (Figure 4.4f).

The adsorption of PVA by soil is modified by the structure of the soil; Williams et al. [1966] conclude that the main structural factor is the pore size. Adsorption of PVA on soil is much less than on dispersed clay minerals. It is aided by the water potential gradient and reduced by other organic materials, which occur naturally on adsorption sites. It is further reported that the surface area of the soil decreases rapidly with the addition of a small amount of PVA. The reduction in pore volume is greater than the volume of the added polymer. It is concluded that molecules would seal the end of the pore and block off the internal surface area a phenomenon known as "peripheral pore occupation".

4.8 Complexes with Polysaccharides

Polysaccharides contain a high proportion of hydroxyl groups. There are neutral and acid polysaccharides whose behavior towards soil and clay minerals differ. Neutral polysaccharides adsorb on the total silicate surface by the formation of hydrogen-bonds and the presence of these bonds has even been used to explain, for example, the interaction of sodium alginate with the crystal edges of soil particles. Acidic polysaccharides in alkaline solution, or in the salt form, have a negative charge which tends to repel them from the negatively charged microns of the silicate mineral. However,

polymer anions can adsorb onto the positively charged sites at the crystal edges by anionic exchange or by the formation of a calcium bridge between the polymer and mineral. Adsorption can also occur on the negatively charged basal planes of the mineral via calcium ions which screen these negative charges and provide an ionic bridge. The bonding of the polysaccharide anions to metal ions, such as Ca^{2+} or Al^{3+} , is weaker than the corresponding interaction with the acid groups of the polyacrylates. Polysaccharide acid groups have lower pKa values and the polysaccharide chain is less flexible than the polyacrylate chain because of its polycyclic nature.

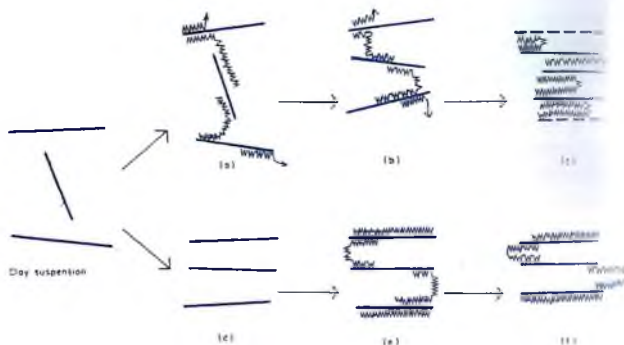


Figure 4.4 : *The effect of poly(vinyl alcohol) as a soil flocculent in the presence of a salt and the effect of the sequence of addition (a) Addition of PVA; (b) Addition of salt; (c) Drying; (d) Addition of salt; (e) Addition of PVA; (f) Drying, [Emerson and Raupach, 1964].*

Studies of the effect of high molecular weight sodium alginate on soil crumb stability led to the conclusion that the polymer is hydrogen-bonded to the edge of the soil particles [Emerson, 1956a,b]. The polymer improves soil crumb stability but the alginate anion is displaced by pyrophosphate, phosphate, or hydroxide ions; observations supporting the concept of a hydrogen bonded polymer clay complex. Lynch et al [1957a] suggested that the adsorption by montmorillonites and kaolinite of various pectinates and alginates involves anionic exchange, possibly with the formation of a calcium ion linkage.

Clapp and Emersson [1972] have proposed the calcium bridging mechanism for complexes between montmorillonite minerals and polysaccharides with uranic acid groups. The degree and strength of bonding depends on the distribution of the uranic acid segments within the polymer, the degree of polymer branching, and the shape of the polymer in solution. Bridging can be broken by a large excess of polyphosphate ions, which compete for the calcium ions at the mineral surface.

Lynch et al. [1957b] studied the adsorption of a wide variety of neutral saccharides, including sucrose, on clay minerals and concluded that adsorption occurs by the formation of hydrogen-bonds and over the total surface including the interlamellar surfaces. Only a small proportion of the polymer could be removed by prolonged washing with water or ethanol, but the complexes were destroyed by N/100 or N/10 sodium hydroxide-evidence that a strong bond is formed. Infrared spectroscopic studies confirm that the polymer-clay bond is a hydrogen bond.

4.9 Complexes with Cellulose

The amount of cellulose adsorbed depends on the nature of its substituent groups and its chain length. Carboxyl cellulose is adsorbed in smaller quantities than methyl or ethyl cellulose and lower molecular weight species are more readily adsorbed. An ionic bonding mechanism, involving carboxylate groups, has been proposed for the adsorption of carboxymethylcellulose by montmorillonites. Hydrogen bonding at the basal silicate surface is the postulated mechanism for the adsorption of a highly branched dextrin (MW 10^6) to montmorillonite [Emerson 1963]. Adsorption is independent of pH, but the complex is dispersed by sodium hydroxide, possibly by hydrolyses of the polymer which degrades to smaller molecules. Clapp and Emersson [1972] suggest the bonding of neutral polysaccharides is by hydrogen bonding and observe that adsorption is increased for higher molecular weight polymers.

4.10 Complexes with Non-Ionic Surfactants

Non-ionic surfactants are either polyglycol esters of fatty acids or polymers such as a poly (ethylene oxide) containing many oxygen atoms in their structure. These polymers adsorb in the interlamellar region of the mineral. The formation of a monomolecular layer of polymer is followed by a bimolecular layer, and possibly by a tri-molecular layer. The nature of the polymer mineral bond does not appear to be discussed in the scientific literature but in view of the hydroxyl groups present, it would appear to be a hydrogen-bond or an ion-dipole interaction.

4.11 Complexes with Proteins and Related Compounds

Proteins, nucleocides and amino acids with basic and acid groups are considered here. Above the isoelectric point, these compounds behave as acid anions (and posses a negative charge) whilst below the isoelectric point they adopt a cationic form of the base. The compounds are only slightly adsorbed onto soil or clay minerals above the isoelectric point, whereas strong complexes form below the isoelectric point. Minerals, such as those of the montmorillonite group, with accessible internal surfaces form interlamellar complexes. Adsorption occurs over the external clay surface also, and layers of up to three molecules thick can form, although the first layer adsorbed at the surface is much more strongly adsorbed than the other layers. The macromolecules, which are adsorbed in cationic form displace metal cations from the clay surface. A small proportion of the macromolecules are adsorbed by another mechanism, possibly by hydrogen-bonding. The material adsorbed on the internal clay surface is protected from chemical and enzymic attack unlike that adsorbed on the external clay surface.

It is established that the proteins; albumin (from egg), gelatin, haemoglobin (from blood), casein (from milk), protamine, pepsin and pancreatin are adsorbed on montmorillonite [Ensminger and Giesecking, 1939, 1941]. These proteins are adsorbed between the silicate sheets.

Proteins can be divided into those which adsorb on both the internal and external surfaces of the clay mineral and those which adsorb on the external surfaces only. The first group comprise proteins of low molecular weight, e.g salmine, or those with minimum complexity i.e high molecular weight proteins with ill defined or globular structures, e.g gelatin, edestin and pepsin. These proteins will spread over any polar surface such as active charcoal and silica. The second group are highly crystalline high molecular weight proteins such as virus proteins.

Pinck [1962] has studied the adsorption of proteins, enzymes and antibiotics on montmorillonite. The behavior of antibiotic varies according to whether they are (a) strongly basic (b) amphoteric, or (c) acidic or neutral. The first group of antibiotics includes streptomycin and neomycin sulfates (average maximum adsorption 186 mg/g of clay) and the second group includes bacitracin and the tetracyclines (average maximum adsorption 307 mg/g of clay). The third group of antibiotics are adsorbed to the extent of 9 mg/g of clay and include penicillin and chloramphenicol.

The tissues of animals and plants contain most of their nitrogen in a basic form or in a form which becomes basic upon hydrolyses. Organic matter derived from these sources will be capable, therefore, of reacting like basic compounds. This should make possible a combination between the basic or positive spots of the organic matter and the acidic or negative spots on the crystal lattice of the clay. In fact, individual particles of clay organic matter will have a greater number of positive spots resulting from free amino groups. Likewise, individual clay crystals, having a cation exchange capacity will have a great number of negative spots. If the two particles should orient themselves in such a manner that there was a mutual attraction between many of these spots, a stable combination would be obtained. In this way the clay crystals must be covered by a "net work" of organic material.

Proteins are built up by amino acid residues arranged in long chains and joined by so-called peptide bond $=\text{CONH}_2=$. In nature, the sequence of amino acid residues along the chain is unique. Some typical features of the side chains are built up by segments, each of these segments can have a polar and non polar character, depending on which amino acid predominates. Polar segments make the chain hydrophilic while non-polar segments makes it hydrophobic. Thus a single protein molecule may have several hydrophobic and hydrophilic segments along the chain (Figure 4.5) [Chandra, 1994], ionic bonds prevail in the hydrophilic region while non-polar bonds are predominant in the hydrophobic regions. This activates the surface of proteins. This surface activity is supposed to be the major cause of the air entraining character of proteins. In their native state, soluble proteins have a unique globular form in which the chains are folded in a manner determined by the amino acid sequences. Parts of the surface of the molecules are hydrophilic with higher concentrations of glutamic and aspartic acids, lysine, and arginine. Other parts are predominantly hydrophobic, with mainly aliphatic amino acids. When proteins are mixed in a material having pH value more than 12, separation and unfolding of the chains take place. It is a type of alteration of molecules known as denaturation and orientation (Figure 4.6) [Chandra and Aavik, 1987]. Thus more hydrophilic and hydrophobic phases are exposed.

The hydrophobic part goes to the air phase (pores and capillaries), and the hydrophilic part goes to the water phase. At high pH values, hydrolysis of the chain takes place, splitting it into parts of lower molecular weight. Proteins form salts with alkalis and complexes through cross-linking with metal ions.

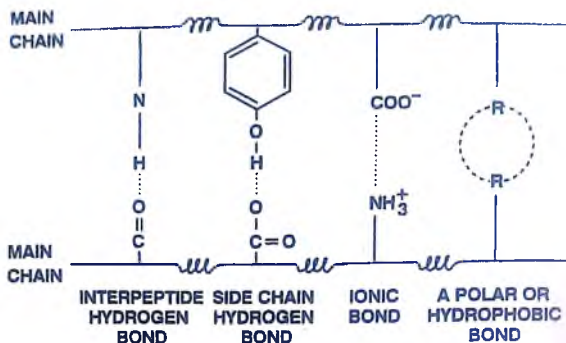


Figure 4.5 : Schematic diagram illustrating the types of covalent bonds;(From Chandra, S. and Aavik, J. *Int. Cem. Comp. Lightweight Concr.* 9 [2], 91, 1987, with permission).

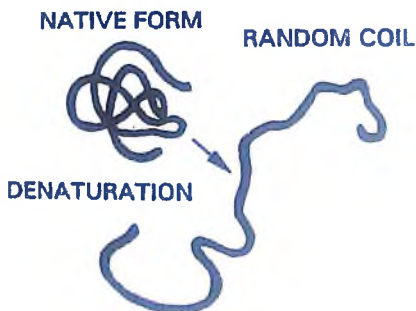


Figure 4.6 : Denaturation of Protein, (From Chandra, S. and Aavik, J., *Int. Cem. Comp. Lightweight Concr.* 9 [2], 91, 1987, with permission).

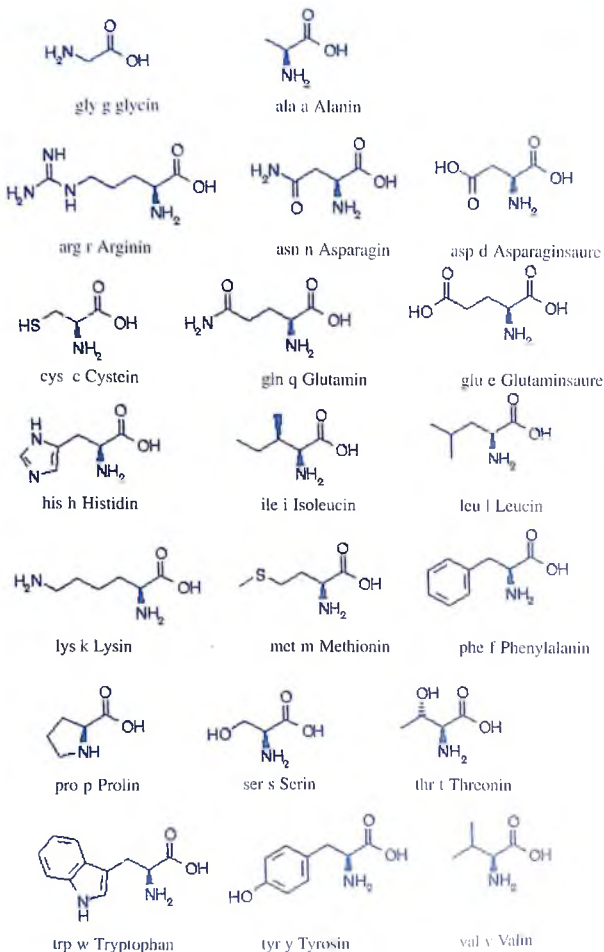


Figure 4.7a : The nomenclature and formula of some of the amino acids.

Alamin	ala a	$\text{CH}_3\text{-CH}(\text{NH}_2)\text{-COOH}$
Arginin	arg r	$\text{HN}=\text{C}(\text{NH}_2)\text{-NH}(\text{CH}_2)_3\text{-CH}(\text{NH}_2)\text{-COOH}$
Asparagin	asn n	$\text{H}_2\text{N-CO-CH}_2\text{-CH}(\text{NH}_2)\text{-COOH}$
Asparaginsaure	asp d	$\text{HOOC-CH}_2\text{-CH}(\text{NH}_2)\text{-COOH}$
Cystein	cys c	$\text{HS-CH}_2\text{-CH}(\text{NH}_2)\text{-COOH}$
Glutamin	gln q	$\text{H}_2\text{N-CO-}(\text{CH}_2)_2\text{-CH}(\text{NH}_2)\text{-COOH}$
Glutaminsaure	glu e	$\text{HOOC-}(\text{CH}_2)_2\text{-CH}(\text{NH}_2)\text{-COOH}$
Glycin	gly g	$\text{NH}_2\text{-CH}_2\text{-COOH}$
Histidin	his h	$\text{NH-CH}=\text{N-CH}=\text{C-CH}_2\text{-CH}(\text{NH}_2)\text{-COOH}$
Isoleucin	ile i	$\text{CH}_3\text{-CH}_2\text{-CH}(\text{CH}_3)\text{-CH}(\text{NH}_2)\text{-COOH}$
Leucin	leu l	$(\text{CH}_3)_2\text{-CH-CH}_2\text{-CH}(\text{NH}_2)\text{-COOH}$
Lysin	lys k	$\text{H}_2\text{N-}(\text{CH}_2)_4\text{-CH}(\text{NH}_2)\text{-COOH}$
Methionin	met m	$\text{CH}_3\text{-S-}(\text{CH}_2)_2\text{-CH}(\text{NH}_2)\text{-COOH}$
Phenylalanin	phe f	$\text{Ph-CH}_2\text{-CH}(\text{NH}_2)\text{-COOH}$
Prolin	pro p	$\text{NH-}(\text{CH}_2)_3\text{-CH-COOH}$
Serin	ser s	$\text{HO-CH}_2\text{-CH}(\text{NH}_2)\text{-COOH}$
Threonin	thr t	$\text{CH}_3\text{-CH}(\text{OH})\text{-CH}(\text{NH}_2)\text{-COOH}$
Tryptophan	trp w	$\text{Ph-NH-CH-C-CH}_2\text{-CH}(\text{NH}_2)\text{-COOH}$
Tyrosin	tyr y	$\text{Ho-p-Ph-CH}_2\text{-CH}(\text{NH}_2)\text{-COOH}$
Valin	val v	$(\text{CH}_3)_2\text{-CH-CH}(\text{NH}_2)\text{-COOH}$

Figure 4.7b : The nomenclature and formula of some of the amino acids.

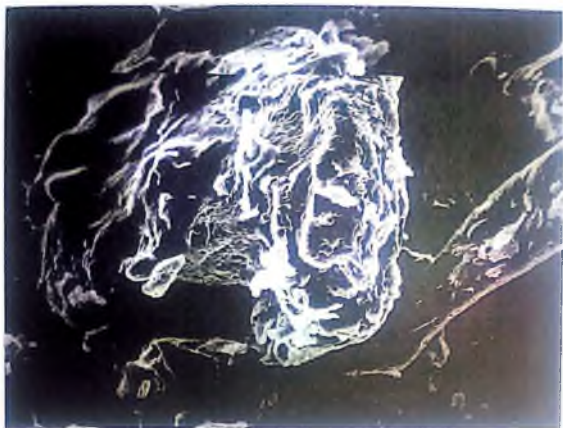


Figure 4.8a : SEM Photograph of raw glutin x 1000.



Figure 4.8b : SEM Photograph of raw glutin x 3000.

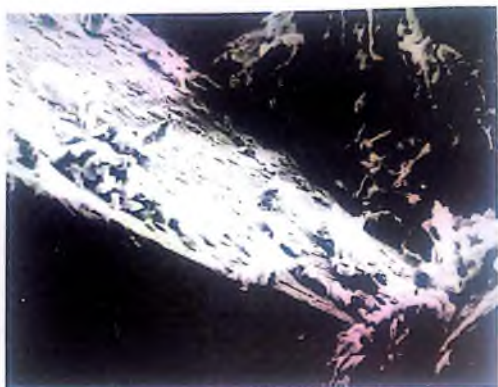


Figure 4.9a : SEM Photograph of stabilized glutin x 10000.



Figure 4.9b : SEM Photograph of stabilized glutin x 3000.

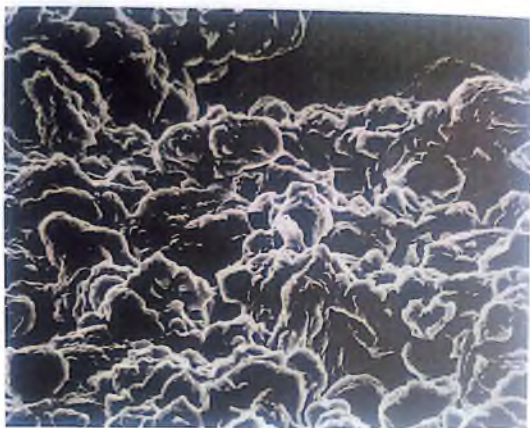


Figure 4.10a : SEM Photograph of BLACK GRAM (Urad ki Dal) x 1000.



Figure 4.10b : SEM Photograph of black gram (Urad ki Dal) x 3000.

Above the isoelectric point, proteins (nucleoside and amino acids) behave as acid anions (and possess negative charge) while they behave like bases below the isoelectric point. The compounds are slightly adsorbed onto the soil or clay minerals above the isoelectric point. Minerals like the montmorillonite group, with accessible internal surfaces, form interlamellar complexes. Adsorption occurs over the external clay surface also. The first layer on the surface is always much more strongly adsorbed than the other layers. The macromolecule that are adsorbed in cationic form displace metal cations from the clay. A small proportion of the macromolecule are adsorbed by the other mechanisms, possibly by hydrogen bonding. X-ray diffraction studies of the adsorption of albumen, gelatin, hemoglobin, casein, protamine, pepsin, and pancreatin on montmorillonite established that these proteins were adsorbed between the silicate sheets [Ensminger & Geisseking 1939 and 1941].

Proteins are adsorbed in the form of cations. In their study on nucleoprotein, Goring and Bartholomew [1952] also reported cationic interaction. Further it is reported that the adsorption was greater when the metal ions present were divalent. Similar results were reported by Kragg and Langston [1962]. These results are sufficient evidence to say that the clay protein complexes are formed by adsorption involving cationic exchange. Further, the most stable structures are those in which a monomolecular layer of macro-molecules is adsorbed. When this adsorption is on the internal surface of the mineral, it is protected from the chemical attack.

The nomenclature and formulae of some of the amino-acids are given in the Figure 4.7.

4.11.1 Scanning Electron Micrographs of Some Proteins.

Some of the materials, which are source of protein used in ancient period in building materials have been analyzed by Scanning Electron Microscope. The material used were raw and stabilized glutin, black gram (*Urad ki Daal*), banana skin. The microphotographs are shown in the Figures 4.8, 4.9, 4.10 and 4.11 for raw glutin, stabilized glutin, black gram and banana skin respectively.

It is seen from the microphotograph (Figure 4.10 and Figure 4.11) that the microstructure of raw glutin which is some sort of ring structure has changed to a fibrous structure when it is stabilized. Black gram has a dense structure with the planes overlapping each other. Dried banana skin has also plate structure with the planes overlapping each other. But it is little different than those observed in the case of black gram.

In another experiment a mixture of non air entrained polymer and calcium hydroxide were mixed to the saturation point. It was done to study the interaction between polymer and calcium hydroxide. This was done till the saturation point. It means that with the further addition of polymer no further reaction took place. The SEM photographs are shown in the Figure 4.12. Well defined hexagonal plates of calcium hydroxide are not seen in the microphotograph.

4.12 Flocculation

Under maximum adsorption of proteins, a multimolecular layer forms and there is little flocculating effect. Maximum flocculating efficiency is obtained when one third of the maximum value of protein is adsorbed. Kragh and Langston [1962] postulated that "initially" the protein forms a disordered monolayer and interparticle bridging occurs as particles collide; with ageing, or agitation of the suspension the monolayer becomes more ordered and the flocculating effect decreases. The effect of pH on protein configuration is more important to flocculation efficiency rather than the effect of pH on the electrical charge of the particles.

It is clear from the previous discussion that the evidence firmly supports the concept of the formation of complexes of clay and protein (and related compounds) by adsorption involving cation exchange. The most stable structures are those in which a monomolecular layer of macromolecule is adsorbed and when this type of macromolecule is adsorbed on the internal surface of the mineral it is sterically protected from chemical enzymatic attack.

4.13 Complexes with Polymer Possessing Amine Groups

These polymers differ from proteins in that they lack acid groups. However it would appear that these are adsorbed in cationic form with ion-exchange. The total surface of the mineral may be involved, but adsorption is limited, in some cases by steric restraints.

Complexes have been formed between polystyrene or poly (methacrylonitrile) and montmorillonite or kaolinite, by first attaching a terminal primary amine group on the polymer:



and then reacting the product with the clay, in the hydrogen form, suspended in a polar nonaqueous solvent [Dekking, 1964]. These complexes are hydrophobic and organophilic. X-ray diffraction analysis indicated the formation of a monomolecular layer with most styrene groups protruding from the basal planes of the mineral. The basal plane is negatively charged and the cationic amine groups are attached to it leaving the hydrocarbon portion of the polymer pendant into the solvent. The ionic bond accounts for the hydrophobicity of the complexes and the orientation of the polymeric hydrocarbon chain is consistent with their organophilicity.

Polyvinyl pyrrolidene (PVP) is adsorbed on montmorillonite and vermiculite, but not in detectable amounts on illite or kaolinite [Francis, 1973]. Adsorption occurs on both the internal and external surface of montmorillonite. As with PVA, the charge balancing cation in the mineral surface has a steric effect, thus the Cs, Mg and Ca forms of this mineral restrict mineral adsorption to monolayers of the polymer but the Na and K forms of the mineral allow double layers.

The mechanisms discussed here are based on individual component, whereas the natural product constitutes of several components such as proteins, cellulose, polysaccharides, fat etc. Addition of these natural polymers significantly improves the properties of mortars and concrete. This can not be attributed due to the function of one component. It is the combined effect of several of them present in a natural balance form. Besides, the ancient builders seldom used single product. Always several of them were mixed in a special order. This way these compensate the negative properties of each other apart from providing some extra property. It shows the wide knowledge ancient builders had about the combinations of different natural materials and the sequence and process of their mixing. Details of the natural polymers used, and the process of their mixing is described in the Chapters 5, 6 and 7.

Besides interacting chemically they also influence upon the crystallization process. Instead of big crystals of preferred orientation, small crystallites are formed, which transforms to agglomerates.

Natural polymers were not only used in India, these were used all over the world. A list of the natural polymers and the date and place of their use is given in the Table 4.8. An interrelation between Natural and synthetic polymeris given in Table 4.9 [Sickles 1981].

Table 4.8 : *Some natural organic materials and the dates of their use [Sickles, 1981]*

	150 Egyptian	46 B.C. Varro's time	23 A.D. Pliny	800 A.D. Rochester Cathedral	Middle Ages		1653 Plac	1703 Neve, Moxon	Mid-1700s	1873 Vicat Smith	1850 Burnell and Periodical
Albumen	X										
Animal Glue	X							X			X
Barley			X						X		
Beer					X	X			X		
Beerswax					X	X		X	X		X
Blood	X	X	X	X		X	X	X	X		X
Butter										X	
Casein	X										
Cheese								X	X	X	X
Cotton											X
Curdled milk		X							X	X	
Dung									X		
Eggs	X				X	X		X	X		X
Eggwhites	X	X			X	X	X	X		X	X
Elm bark			X								
Fig juice	X	X	X						X		
Fruit juice					X	X			X		
Gluten					X	X			X		
Gum arabic	X					X	X				X
Hogs lard		X	X					X			X
Keratin	X										
Malt					X	X					
Milk		X	X					X	X	X	X
Molasses										X	X
Oil			X					X		X	X
Rice											
Rye dough		X							X		
Saffron			X								X
Shellac											X
Size			X		X	X					
Sugar					X	X				X	
Tannin			X								
Urine					X	X					
Vegetable juice									X		
Wine			X								
Wort					X				X		

Table 4.9 : Interrelation between Natural and Synthetic Organic Materials

Type of effect	Desired admixture	Natural materials	Synthetic materials
Accelerator	Accelerate setting and early strength development	Egg whites, elm bark, barely water, fig juice, rye dough, hogs lard, curdled milk, blood starch, colostrum, gum mastic, sugar	Calcium chloride, triethanolamine, calcium formate, epoxies, urea with barium hydroxide
Adhesives	Increase bond	Rosin, modified rosin, gelatin animal glues (especially hides), gluten, vegetable glues, casein, blood, albumen	Acrylic resins: acrylic polymers, acrylic emulsion, epoxy polymer, rubber, butadiene-styrene, copolymers, polyvinyl chloride (PVC), polyvinyl acetate (PVA)
Air entrainer	Improve durability, especially freeze-thaw resistance	Malt, beer, urine, animal hides (salts of proteineous materials)	Alkyl-aryl sulfonates, some synthetic detergents, salts of ligno-sulfonates, alkylbenzene sulfonates, petroleum fractions, barium hydroxide, sulfonated hydrocarbons
Emulsifiers/ stabilizer	Stabilize an emulsion	Egg yolk, oils, fats, waxes	Benzophenones, benzotriazoles, acrylonitriles
Fillers	Improve hardness	Size, glue, gum arabic, talc, sugar, saccharine, fruit juices, gluten, rice	Coarse fluid coke, acrylic polymer, emulsion binder, acrylic emulsion, sodium borosilicate glass
Gas former	Cause expansion when setting	Vegetable glue, animal glue	Resin soap, hydrolyzed proteins, aluminium powder, saponin
Modifiers	Alter existing solutions	Proteins, egg whites, hemp seed, blood, gluten, keratin, collagen, casein, gelatin, borax, natural resins	Some acrylics: acrylic polymers, acrylic emulsion, acrylic powder, polyvinyl acetate (PVA)

Table 4.9 : Interrelation between Natural and Synthetic Organic Materials

Type of effect	Desired admixture	Natural materials	Synthetic materials
Nonshrinking agents	Prevent shrinkage	Beeswax	Water-soluble resins: formaldehyde, cellulose derivatives triethylene, glycol, glycol ester, styrene-butadiene copolymers, pyrogenic silica Fluid coke, aluminium powder, silica gel acrylic emulsions
Plasticizers/modifier	Give plasticity, reduce brittleness soften, increase workability	Sugar, milk, egg whites, slurried dung, turkey red oil, animal glue, glycerine, glucose, soybean lecithin, Mineral oil, rosin, non-drying oils, linseed oil, hogs lard, figs	Hydroxylated carboxylic acids, salts of ligno-sulfonates, silicones, vinsol resin or phenol-formaldehyde resin, sodium borosilicate glass, epoxies, phosphates, glycolates, polybutenes, phthalates, acrylic emulsions
Solidifier/rigidifier	Increase hardness or stiffness	Sugar, vegetable glues, treacle, molasses	Silicones, silane, coupling agents, baryta, polyurethanes
Strengtheners/binder	Improve strength of solution	Keratin, casein, elm bark, hot barley water, tannin, size, linseed oil, walnut oil, cow/ox/human hair, chopped straw, rice, rye dough/egg whites, fibrin in blood, cotton flock, jute, sisal, gum arabic or tragacanth, animal glue from Rhodes, fig juices with egg yolks, sugar	Some acrylics: acrylonitrile, acrylic emulsion acrylic polymer, emulsion binder, nylon fluid coke, polyvinyl chloride (PVC), polyvinyl acetate (PVA), polyethylene, terephthalate, polythene, propyl alcohol
Super plasticizer	High flow	Albumen	Melamine formaldehyde sulfonates, naphthalene formaldehyde sulfonates, salts of lignosulfonates

Table 4.9 : Interrelation between Natural and Synthetic Organic Materials

Type of effect	Desired admixture	Natural materials	Synthetic materials
Waterproofing, damp-proofing, and repellent	Decrease permeability	Animal glue plus tannin, bitumen, wax, emulsion, mineral oil emulsion, beeswax	Soluble chlorides, calcium stearate, aluminium stearate, ammonium stearate, butyl stearate, methyl groups, stearic acid, oleic acid, polyurethanes, polysulfide sealant, epoxy resins with silicones, epoxy-terminated polyurethanes, silicones, silane coupling agents, silicon resin with mineral spirits, sodium methyl silicate with water polyvinyl acetate, fluid coke, acrylic resin
Water reducers	Reduce amount of water required for a given consistency	Sugar proteins	Sale of lignosulfonates, hydroxylated carboxylic acids, gluconates, heptonates, polysaccharides, tartrates, citrates, silicones, melamine formaldehyde sulfonates, naphthalene formaldehyde sulfonates

4.14 Botanical Family Names of Some of the Natural Polymers

Aata : Wheat flour

It contains about 80% carbohydrate, 6-12% proteins, and thiamin, riboflavin, niacin, pyridoxine and pantothenic acid. The major constituents of carbohydrate are starch, sugar, cellulose and hemicellulose. The major proteins are, albumin, globulin, protamine and glutelin.

Its use in plasters and concrete produces adhesiveness, air entrainment and provides good plasticity, workability, and introduces hydrophobicity in the structure.

Gum from Acacia: Auriculiformis**Alsi:** *Linum usitatissimum* Linn

Flax-Flax is extracted from the stalks of linum types specially grown for this purpose and harvested when the capsules are immature. The fiber is valued for its strength, fineness and durability. It is stronger than cotton. It is soft, lustrous and flexible and possesses high water absorbency. It has low elasticity and is stronger when wet than when dry. Flax has good resistance to moisture and mildew.

The seeds contain cyanoglycosides, linamarin. The seeds contain about 30 to 40% of fixed oil, 6% mucilage, 25% proteins, together with wax resin, sugar phosphates and a small quantity of the cyanogenic glycoside, linamarin. Cultivated through out India.

Arjun: *Terminolia arjuna*, (Cambretaceae) arjuna

It contains crystalline compound arjunine, a lactone, arjunetin, essential oil and tannin, It grow throughout the greater part of India, in the sub himalayan tract, Chota Nagpur, Madhya Bharat, Madhya Pradesh, parts of Bombay and Madras.

Bahera: *Tectona, belisica* Rexb

Fruits; bitter, astrin, tonic, contain 17% tannin.

It is found through out the forests of India below elevations of about 3000 feet except in the dry and arid region of Sind and Rajputana.

Bathua: *Solanum xanthocarpum*, *Chenopodium album* Linn

A common prickly herb. It contains essential oil and carotene. It occurs chiefly in the cultivated ground. It is also cultivated as a pot herb.

Bel friut pulp: *Aegle* (Rutaceae) marmelos

The fruit contains marmalasin. It is identical with imperatorin. Young bark contains coumarin 0.6%, alkali 0.003% and umbeliferone. matured bark contains 0.3% alkali, alk. Aehgelenine identical with figurine isolated from *zanthoxylum coco*. Mucilaginous substance of the fruits is used as gum and in varnish.

It is wild and grows in the sub himalayan tract, central and south India, Often found all over India.

Besharam: *Ipomoea carnea*

It contains, lignin 16.59%, cellulose 57.73%, Ash 6.45%, Pentosan 17.30%, Silica, 0.16%.

It is grows wild in India and is known as Besharam locally in Madhya pradesh, central India.

It is used in building material. It works as an adhesive and improves the strength.

Bhatkataiya: (*Solanum indicum*)

Its root contain carmine. The fruit contains enzymes, alkali, solanine, solanidine in roots and leaves. It is grown through out tropical climate India.

Bhaulbhari: *Mimusops Elengi*

Bark contains estrin, seed contains saponin, kernel yields an oil.

It is grown in the Western Peninsula, Southward from Khandala Ghat on the west and the North Circars on the east side and the Andamans.

Bhilawa: *Semecarpus anacardium* Linn

It contains anacardic acid, cardol, catechol, anacardol and fixed oil, semecarpol, bhilawanol. It is found in the sub-himalayan tract from the Beas eastwards, ascending in the outer hills, Assam, Khasi hills, Chittagaon etc.

Chichiri: *Capparis spinosa* Linn

Flower buds contain rutin-glycoside, 4% pentosans on dry weight basis also contain rutilic acid, pectic acid, a volatile emetic constituent, saponin etc. Seeds produce 34-36% oil. It is found in the plains between the Indus valley and the river Jhelum. Low inner valleys of Himalayas, Chamba, Kumaon, Nepal, Deccan, west Ghats etc.

Coconut: *Cocos nucifera* linn

Shell of coconut is used for handicrafts, mesocarp (fiber) is used for coir manufacturing. The coir is applied to the short, coarse rough fibers which make up the greater part of the husk of the fruits of coconut palm. It is a good insulating material. It stays cool in the hot weather and warm in the cold weather, tough, hard wearing and economical. Coir dust, a waste product in the coir industry is an excellent surface soil mulch. In combination with cement, the dust is a thermal insulating material. It can also be used for building slabs or for hard boards.

Cotton: *Cossypium* sp.

The bulk of cotton production is consumed in the manufacture of woven goods. Products in the form of yarn and cord include unwoven type cord, thread, cordage and twine etc. Cotton constitutes of the basic raw materials for cellulose industry including plastics, rayon and explosives.

Deodar: *Cedrus deodar*

Gum from Deodar contains cholesterol, essential oil. It is found in the north west himalayas from Kashmir to Gahrwal.

Dhaiwan tree: (*Cordia macleodii*)

It is found in Chota Nagpur, Madhya Pradesh, Deccan and Karnatak.

Ganna: *Saccharum, officinarum* Linn

It contains sugar, it also contains calcium oxalate. Cultivated in the hotter parts of india

Gugul: *Balsamddendron Mukul*

It is a gum resin. The commercial product contains 1.45% essential oil besides gum and resin. It is found in Bellary, Mysore, Deccan, Khandesh, Kathiawar, Rajputana desert, Sind and Baluchistan.

Gur: Brown sugar

It is made by boiling juice of sugarcane till dryness. It is unrefined sugar.

Kaitha: Elephant Apple, *Feronia timmonia* (tinn), *Correa*

Gum obtained from the trunk and branches is used like gum-arabic, *Feronia elephantum* (corred). Fruit contain triterpenoid substances. It is cultivated in different parts of India.

Kajal: Carbon black

It is made by putting a cover over the oil lamps

Kanj, Kharmanthari: *Toddaliaculeata*, *Asiatica*

It contains essential oil, barberine. The leaves contain a alkaloid glycoside, toddalin. The root bark contains the toddaline and toddalinine, toddalolactone, resin and glycosides. It is found in Deccan, In all districts of Madras state, Kumaon.

Kundru: *Cephalandra Indica* Naud, *Cococinia*

It contains enzymes, hormone, and traces of an alkaloid. The juice contain an amylase. It is found all over India

Kusom Flowers: *Corissa*, *tinctorius*

It contains essential oil which ranges from 20 to 30%. The coloring matter in these flowers is Casthanin.

Machphal, Madanphal (*Artemesia, compositae*) **vulgaris linn, Randia Dumetorum LMMK)**

Essential oil, plant yields 0.2% volatile oil, oil good larvicide and a feeble insecticide. Fruits contain neutral and acid saponin, essential oil, and acid resin. Neutral saponin is the active constituent and lead in seeds. It is found in the sub himalayan tract from the Rawalpindi district, and further eastwards ascending Sikkim. Southwards extends to Chittagong and Peninsular India.

Mahua: *Madhuca Indica*. Syn. *M. Latifolia*, *Bassialatifolia*

Mahua oil extracted from seeds remains fluid in major part of the year but in cold weather it solidifies to a buttery consistency. Refined oil is used also for candles, as hatching oil in jute industry and as a raw materials for producing stearic acid.

Flowers yield a distilled spirit which contains triterpenoid substances. Glucosidic saponin is contained in leaves. It is found in northern India, Dehradun, Saharanpur, U.P., Bihar, cultivated or can be self sown.

Manjitha, Majistha: *Rubia cardifolia* Linn.

It contains sterols and the quinone munjistin. Stem is used in cobra-bite. It is found in all the hilly districts of India.

Moong: *Phaseolus aureus* Roxb. Eng. Green Gram

It contains proteins. It is vastly cultivated in India

Fruits of Nagbala: *Sida spinosa*

It is found in the hotter part of India from N:W to Ceylon.

Nariyal ka pani: *Cocos (palmae) nucifera* Linn.

The milk contains histidine, arginine, lysine, tyrosine, tryptophan, proline, leucine and alanine. The fruit yields oil ranges from 57 to 75%. The oil contains; lauric, myristic and fatty acids, and other triglycerides. Cultivated in the hot damp regions of india, specially near the sea.

Neem: *Azadiracta Indica*, A Juss. Syn. *Melia Azadiracta* Linn

Seeds contain up to 45% oil, bitter constituents separated form nim oil-nimbin, nimbinin and nimbidin:nimbidin main active constituent and contains sulphur.: Blossoms yield a glucd.:limbosterin (0.005%) and 0.5% of a highly pungent essential oil: nimbosterol, nimbecitin and fatty acids.

The neem gum is a stimulant and demulcent tonic. The fermented soft which exudes from the trunk is a refrigerant and alterative tonic. Seed oil is applied as an antiseptic dressing in leprosy and chronic skin diseases. It is found all over India.

Petha: *Cucurbita pepo* Linn, Benincasa (*Cucurbitaceae*, *cerifera*)

Eng. Summer squash, pumpkin, Safed Kaddu

Oil from the seeds contains anthelm. It is cultivated all over India.

Raal: *Vateria Indica* Linn (linn), *Depterocarpaceae*- Eng. white damar

It is a fatty oil from a fruit, damar resin. A resin obtained from the trunk is used as an incense and is also used in paints and varnish. It is found in the western ghats and south India.It is found in western India from North Kanara to Travancore.

Rice: *Oryza sativa* Linn.

Cereal contains a high percentage of carbohydrates together with a considerable amount of proteins and some fats. In the wall of seeds become fused with the ovary wall to form the husk.

Rice is of different types. Glutinous rice when cooked produce a thick sticky paste. Glutinous rice has been used with lime in the ancient period for joining the stones, rocks etc. Rice starch is much used in European countries. The rice straw is used for making straw boards, paper and mats. Oil from rice is used for making soaps and cosmetics.

Riti Antiaris: *Mraceae toxicaria*

It contains the cardenolides. Alfa-antiarin, beta antiarin, gama antiarin, antiaresin, toxicarin. It is found in the evergreen forests of the west ghats from Konkan southwards to Travancore .

Safeda: *Populus, Salicaceae*

Leaves contain the phenolic glycosies, pupulin, salicin. It is found in north west himalayas

Gum of Salai: *Boswellia (Burseraceae. Serrata)*

Gum resin-essential oil 9.0%. Two varieties are distinguished: serrata with serrate and pubescent leaves, and var. glabra with entire, glabrous leaves. It is found in Madhya Pradesh, Deccan, Bihar, Orissa, Rajputana, Eastern states and N. Gujarat.

Gum of Saral tree: *Pinus roxburghii*

It is a resin and contains 40% alfa and beta pinene. It is found in the outer himalayan ranges from the Indus to Bhutan.

Saras: *Cupressus sempervirens* Linn.

Leaves yield essential oil 2.0% containing 80% alpha pinene, wood yields 2.555 essential oil. Essential oil from the leaves has vermifuge properties. The tree is a variety only known in the cultivated state in N.W. India. The wild form is a native of Asia minor.

Sehund ka ras: *Euphorbia nerifolia*. Linn.

It is found in Orissa and Deccan, also cultivated elsewhere in India.

Semul ke phool : *Salmalia malabarica*

Gum contains catechon-gallate, seeds contain 22.35 crude fat with 0.5% stearin. Roots of young plant contain proteins, fatty compounds 0.9%, phosphatides (cephalin) 0.3%, semul red 0.5%, tannins 0.4%, arabinose and galactose 8.2%, pectic compounds 6.0%, starch 71.2%, mucilage appears to be salico-phosphoric acid of mannogalactan. It is found throughout the hotter part of India.

Sugarcane: *Saccharum officinarum* Linn

The mother liqueur left after crystallization of sugar is known as molasses that contains 30-35% sugar. Wild orange tree

Dry fruit of Tendu: *Diospyros melanoxylon* Roxb.

Bark 19, fruit 15 and half ripe fruit 23% tannin. It is found in the deciduous forests of the Madhya Bharat, Chota Nagpur, Bihar and West Peninsula.

Vachnag: *Acorus Calamus* Linn, (Aconitum, Ranunculaceae, ferox Wall)

It is toxic and contains alkoids pseudaconitine, Glucd. acorin, essential oil, dry rhizomes contain 1.5-3.5% of yellow aromatic volatile oil, essential oil containing calomen, calamenol, calameneon, asarone. Besides asarone it contains small amounts of sesquiterpenes and sesquiterpenoic alcohols. Odor of oil ascribed to an unidentified constituent. Fresh leaves contain oxalic acid 0.078, calcium 0.006%, and dry leaves contain oxalic acid 2.0, calcium 0.18%. It is found in the Alpine Himalayas of Assam and Nepal.

Concluding Remarks

Natural polymers had been used long before Christ. These were mostly agro-products found in nature. Some other products have also been used like, milk products, sugar compounds, oils, blood and eggs. All these natural products contain various proteins, cellulose, polysaccharides and fat. These work as air entraining agent, produce viscous mass, increase adhesiveness, and increase resistance against water penetration. They also interact chemically and produce complexes, which are hydrophobic. These if do not fill up the pores, at least seals them. This significantly decreases the permeability.

It is to be noticed here that the ancient builders did not use one single polymer, always two or more have been used together. This compensates the negative properties of each other. For example, insecticidal polymers when used biological damage is precluded.

The ancient builders have vast knowledge about the natural polymers. These were carefully chose considering the type of work, and were used in adequate manner. The process of their preparation is long and thus time taking, produces quality material.

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5 LIMEWASHES

Limewashes are the suspension of hydrated lime in a saturated solution of lime in water. This has been in use since ages for the purpose of decoration. Apart from the aesthetic effect the mild antiseptic properties, as well as the sanitary influence of the clean bright surface produced has long been recognized. White washing is thus a primitive, but a quite effective, sanitary measure. It is customary in India to whitewash the house after monsoon period before starting of the winter. This is the time when the preparations for the festival "*Diwali*" are done. During "*Diwali*" amongst others, goddess "*Lakshmi*", the goddess of wealth is worshipped. It is a legend that if the house is not clean the goddess would not come. But scientifically, the reason is highly hygienic. Whitewashing kills the bacteria and other insects which have cropped up during monsoon period. Behind each legend, there is always a hidden scientific background.

Limewash is a traditional painting material which has been popular because of its cheap and easy production. Besides, its benefits such as matt appearance and high water vapour permeability limewash has some disadvantages such as complicated application and low weathering resistance. Various additives have been developed to improve the performance of limewash. These are both inorganic and organic additives. Inorganic additives are salts like common salt, alum etc, and organic additives are mainly case in (milk protein), linseed oil, and more recently paste (methyl cellulose) and polymer dispersions.

5.1 Plain Limewash

Limewash is a dispersion of calcium hydroxide particles in an aqueous solution of approx. 1 g/l Ca(OH)_2 . It is made by putting lime in water for a long time. Lime putty which has been stored for long time with a water content of 52% by mass can be used. It is thinned with water to the suitable concentrations. This, however, easily rubs off, and disappears almost entirely if exposed to the weather for some months.

5.2 Lime-Salt Washes

A plain lime wash can be greatly improved by the addition of common salt, in the proportion of 15lb common salt to 50lb. of hydrated lime or the putty obtained by careful slaking of quicklime, with 7.5 gallons of water. If available, 5lb. of dry calcium chloride (technical quality) may be used instead of common salt. It produces a cheap and strongly adherent wash. Either of these salts increases the solubility of lime, and the degree of penetration; it holds the moisture, and facilitates the carbonation of the lime after application.

5.3 Additives for Limewash

5.3.1 Limewash with Glue

Finck [1922] has tested a number of whitewashes, which were exposed to the full weather effect for a period of 3 months. It is reported that the addition of plain glue, whiting or flour paste improves the properties of limewash. For making limewash with glue, about one-twentieth part of the glue to the weight of lime is used, lime to water ratio being the same as for plain limewash. However, it was found that when glue was added, lime alone gave better results than when added together with whiting. The addition of sodium silicate "water glass" gave no improvement in performance, and that the addition of small quantity of alum improved the workability. Whilst formaldehyde improved the weather resistance. For dry interiors, a simple non-rubbing composition is recommended;

"3lbs. of glue dissolved in 2 gallons of water, and added slowly to a cream made with 50lb of hydrated lime."

Another simple type of whitewash is made of whiting—finely divided calcium carbonate or chalk—suspended in thin glue or size water. But it does not come under the category of limewash as it does not contain lime.

5.3.2 Cold Water Paints

In the cold water paints, most of which are essentially lime-caseinate paints, an adhesive or cement-forming material is present; an "extender" in the form of excess hydrated lime, whiting, zinc oxide etc.; colouring matter if required; and usually some preservative to prevent putrefaction of the organic constituent before application, or appearance of mould afterwards if applied to a damp wall.

Lime Casein Water Paints

Series of tests performed by Finck [1922] as mentioned earlier have shown that the casein addition has produced the best results. The amount of casein depends on its ability to combine with the lime to form a compound, calcium caseinate, which becomes insoluble on exposure to air. Solution of the casein is facilitated by the addition of several basic substances, the best of which proved to be in this trials, to be (tri-basic) sodium phosphate, which is strongly alkaline in solution. This gave better results than ammonia, washing soda (soda ash), sodium silicate (water glass), caustic soda (lye) or borax, though the last can be substituted for the sodium phosphate in the composition given here without much harm. Amongst the mixtures tested the best results were shown by lime, casein and whiting, with the addition of sodium phosphate and formaldehyde (formalin). This produces a cold water paint, which does not rub off, and is quite weather resistant. Neither common salt nor sodium fluoride improved theses properties. when added in small proportions.

For a cheaper paint, though still of good weather resisting and non-rubbing properties, the whiting can be replaced by twice its weight of lime. Where borax is used in the place of sodium phosphate, this acts as a preservative, and the formaldehyde is therefore omitted.

Casein is prepared from separated milk on large scale by souring or by acid treatment. It is sometimes a little difficult to wet it thoroughly in order to get it into solution, so that it is recommended to soak in hot water for a couple of hours as a preliminary treatment. The lime cream is preferably made up some hours in advance of use, to ensure thorough slaking and disintegration. If quicklime is used it should be fat, easily slaking lime; the resulting paste after slaking should be passed through a fine sieve before use, and both casein solution and lime cream should be quite cold before mixing. For small quantities at least the use of ready hydrated lime is recommended. The mixed paint must be used within twelve hours.

The following composition will give a first quality weatherproof wash: soak 10lb of commercial casein in 4 gallons of hot water, until thoroughly softened: dissolve 6lb. (tribasic) sodium phosphate in 2 gallons of water: add this solution to the casein with constant stirring until all dissolved. Make a thick, smooth cream of 25lb. whiting and 50lb. of hydrated lime for the putty made from quick lime; carefully slaked and screened. Add the cold casein phosphate solution to the cold lime paste, stirring constantly. Just before use add slowly and with vigorous stirring a solution of 5 pints of ordinary commercial formalin (formaldehyde) in 3 gallons of cold water.

Borax can be substituted for both the (tri-basic) sodium phosphate and formaldehyde if the latter are not available; tinting colours can be added as desired. The formaldehyde must be added slowly, with constant stirring, as otherwise the whole may turn to jelly and be destroyed.

A rather cheaper cold-water paint is obtained by replacing 25lb of whiting in the above composition, by 50lb hydrated lime. Another excellent lime-casein paint for use on damp walls uses ammonia to get the casein into solution; 5lb of casein are soaked in 2 gallons of hot water, and a solution made with 3 pints of commercial strong ammonia solution diluted with a gallon of water is added, and the whole stirred until the casein dissolves completely. Then this is added to the thick cream made with 50lb. hydrated lime (or by soaking, as before 1/2 bushel quicklime) and 2 gallons of water, and well stirred. Just before use, a solution of 5 pints of formalin in 3 gallons of water is added slowly and with constant stirring. The resulting paint can be thinned as desired, and should be used within a day after mixing.

If hydrated lime is used, it is practicable to mix the materials dry, and to make up small quantities with water to give a working consistency; the formaline is added as before, in the same proportion, and just before use.

Herm *et al.* [1993] have studied the influence of casein, potassium oleate, and some surfactant. All used additives are water soluble and show surface active properties. Their molecules are supposed to concentrate at interfaces such as the surface of the dispersed calcium hydroxide (or calcium carbonate particles).

Casein: Milk protein, dissolved in water by addition of 0.53 m mol $\text{Ca}(\text{OH})_2$ per g casein. Casein is a protein with serine phosphate as specific functional groups. Under basic conditions it dissociates forming anionic phosphate groups. Casein shows strong surface active behaviour and can be classified as an anionic surfactant [MORR, 1979].

Potassium Oleate ($\text{KO}_2\text{C}_{18}\text{H}_{33}$): It is very likely that linseed oil, being a tri-glyceride of different unsaturated C_{18} - fatty acids, is hydrolyzed when mixed with lime due to the strong basic condition ($\text{pH}=12$). In this case, glycerine and calcium salts of the fatty acids are formed.

Potassium oleate was used as a substitute for linseed oil, since the oil is immiscible with water. Potassium oleate is also known as anionic surfactant.

Surfactant: This commercially produced, di-quaternary silicone surfactant was tested as a substitute of the natural substances. It belongs to the group of cationic surfactant.

The experiments have shown that the additives to limewash, historic types (Casein and linseed oil) as well as a modern silicon surfactant, influence the properties of lime. As the additives are surface active substances, their molecules are adsorbed by the lime particles, and thus keeps the particles in well dispersed form.

Casein can act as a liquefier and it increases water vapour permeability. Linseed oil as well as potassium oleate increase the yield values and reduce water vapour permeability. The most favourable effects of the silicone surfactant are the stabilization of lime dispersion, and the acceleration of carbonization.

Polymer-Lime Paints

In the last decade polymer-lime paints have been developed and are extensively used. These paints produce very smooth and brilliant surface and provide water repellency. But this is for a short time. It is very often noticed that there are cracks and the paint is chipping off the surface. It is because the polymer paint makes a film on the wall surface. It is hydrophobic and seals the pores. Thus the moisture transport from the walls to the atmosphere is hindered. This moisture condenses and accumulates on the inner surface of the paint and develops hydrostatic pressure. When this pressure is higher than the strength of the paint layer it bursts out and produces cracks; paint chips off like thin plastic film. These films chip off in parts, whilst at some places it still sits hard adhering to the wall surface, and it is not easy to take them off. A typical example of paint chipping off is shown in the Figure 5.1, and detachment of the polymer-lime plaster in the Figure 5.2. The polymer plaster is detached and the stones and bricks are exposed. It is clearly seen that this detachment did not occur uniformly. The aggressive elements; pollutant gases, acid rain etc. will easily penetrate through these openings and will further damage the building.

The cost involves in taking off these films and the plaster and cleaning the wall surface for repair is very high. These are good for a short time but

in the long run, they create more problems than existed before their use. The cost of cleaning is often much higher than the cost of painting.

Lime-Casein-Linseed oil Paint

Chipping off problem does not occur when the limewash is made using casein and linseed oil. Instead of making a film, these interact with the calcium hydroxide and make complexes. These complexes occupy the empty space: pores and capillaries; which are filled up or at least sealed. Due to this the porosity may not be so much effected but the permeability decreases significantly. Thus the paint does not sit on the surface only physically, it is a physico-chemical phenomenon. Potassium oleate has shown promising results as a substitute for linseed oil [Herm *et al.*, 1993]

It is true that it takes longer time to dry compare to the polymer-lime paint, but it is much more durable and last for longer time. It creates hydrophobicity; is antiseptic and resistant to aggressive environmental conditions. Besides, it is an environmentally friendly material. This was used in the ancient time, no rubbing off or chipping off of the paint is reported. Some of the buildings painted with this type of paint are still in good condition after long period of time

5.3.3 Coloured Limewashes

Coloured limewashes are made by the addition of pigments. A lot of pigments are available which can be used. The pigments should be "lime fast", i.e., not affected by free alkali, which will be present in the form of uncombined lime; if other than those directly recommended be used, preliminary test should be made with a small batch to ensure that these work well. For grey and dark tints, ivory, bone, and carbon black have been recommended; for a dense white, zinc white and lithophone have been added to the lime-caseinate paints. For red there are vermillion, Indian red, Venetian red, and Carmine lake. The ochres and siennas are all lime fast; for yellow colour, there is available yellow ochre, sienna, and naples and cadmium yellow. For brown ochre, sienna, umber, vandyke and cassel brown; for blue, ultramarine and cobalt blue are recommended, whilst for green; emerald green and permanent green have been used. Some caution should be exercised in connection with lake colours in general; it is stated that pigments which have been precipitated on a basis of calcium sulphate are to be avoided in limewashes.



Figure 5.1 : Chipping off polymer-lime paint from the wall surface [Photo, Chandra].



Figure 5.2 : Detachment of polymer-lime plaster from the walls, exposing bricks and stones [Photo, Chandra].

In India generally yellow ochre "*Ramraj*" and blue vitrol "*Tuttia*" are used. Yellow ochre produces yellow colour and blue vitrol produces blue colour. The primary colours are five; white, yellow, red, black and blue. Mixing these colours in different proportions produce different colours and tones. For example blue and yellow mixed together produces green colour.

5.4 Applications

Either glue or casein limewash can be used as sizing coats on walls before painting or papering. In applying them, the wall should always be thoroughly cleaned by scraping and brushing, any old whitewash, paper, grease and dirt being carefully removed before putting on the new coat. The surface should not be too dry. Quite a thin coat spread on quickly by a large brush, or air spray, gives the best results. A gallon of the lime wash should cover about 200-250 square feet (less on brick); with a 4 inch brush some 20 to 40 square yards per hour is stated to be reasonable rate of application. The coat of the more expensive lime-caseinate paint amounts to a few pence a pound only, depending upon local prices for casein and formalin.

A possible development in the direction of the use of a cheaper vegetable protein to replace the casein, such as from the castor-oil bean, should be noted here; mention-must also be made of some work carried out recently on water proofing distemper by the addition of gum resins and lime soaps to a lime-caseinate body.

Concluding Remarks

Limewashes have been in use from the time immemorial. Basically for the general understanding it was done because of the aesthetic reasons; it looks good and decorative. But there is a very solid scientific reason for doing this. Generally, according to the old tradition the whitewashing painting etc was done after the monsoon period before the festival "*Dewali*" which falls during the beginning of winter, mostly in the month of October. During monsoon period, humidity and temperature rises, which give birth to a lot of bacteria and insects. Apart from this, high humidity and high temperature also influence the plasters on the walls and ceiling which deteriorates. Very often this is noticed by the formation of white spots on the wall surface. This decreases the strength and life of the dwellings. Cleaning and whitewashing strengthens the structure, and being antiseptic kills the bacteria and insects; thus it is very good from hygienic point of view also. It creates a very healthy feeling

While it is clear that the limewashing of the dwellings is very good, it is utmost important to select the right type of limewash. All limewashes do not possess the same properties. Mostly these are selected basing upon the price, but some times even if the expensive limewashes have been used these have short life and creates extra problem like in the case of polymer-limewashes. It is recommended to keep the old tradition and use limewashes and paints made traditionally using natural materials and oil.

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6. PLASTERS

Plaster is defined as any material used in a plastic state to form a durable finishing coat to the surfaces of walls and ceilings of a building. Plaster is rarely called upon to sustain any great load: it suffices if it is strong enough to support its own weight, together with that of any enrichments forming ornamental work; that is, the keys formed behind the laths must not shear off owing to stresses set up by a moderate amount of vibration or by any subsequent small movements of the building; and if at an early stage sufficient strength is developed to allow of the application of a second or third layer of plaster over the first coat. Since such a moderate amount of strength is easily attained, the most important quality in a plaster is freedom from cracking and “pitting” or “popping”.

Plaster consists of binder which can be clay, lime or cement and aggregates, which is generally sand. It is the mixture, which is applied on the walls. It strengthens the wall and thereby prolongs its life length. It gives smooth surface. Colours can also be mixed in it, which provides a pleasant look to the building. Various civilizations have adopted different techniques to protect and fortify the walls as well as to beautify them in their own style. The plasters became a reflection of the lifestyle, wisdom and skill of the people of a particular civilization. It has thus become an integral part in the construction of a habitat.

Mankind has used plasters for multiple purposes. Sometimes the primary objectives have been to ensure the longevity of the walls and offer protection. At times it has served as a base for paintings or it has incorporated relief work.

6.1 Different Styles of Plasters

The Indus valley people used plasters in their houses made of lime, clay and gypsum. One of the earliest literary references can be found in the part “Chuluvagga” of “*Vinay Pitak*” of the 3rd century B.C. The plasters were developed in different periods basing upon the job requirement they have to fulfill. These were called as “Style” of that period or Style named after the place where they were used. Some of the examples are: *Vinay Pitak Style*- 2nd century B.C, *Ajanta Style* – 5th century A.D, *Bagh Style* – 7th century A.D, *Jaipur Style*- 16th century A.D.

The *Vinay Pitak Style* plaster was mostly used for plastering the rooms of Buddhist monks residing in the monasteries. This was a mud based plaster. There was no damage to the plaster in the bottom as it was supported by teak wood panels. But the top layers kept falling off. This problem was solved by using a mixture of ash and calf dung in the plaster. By the 2nd century B.C special plasters were developed to be used on the walls as a base for making paintings. These were also applied by special techniques developed. Example of the use of such plaster is in the wall preparation for paintings at Ajanta caves which was named as plaster of *Ajanta Style*. By the 5th century A.D, there was immense development in the material used in making the plasters and application techniques. It is referred in "*Vishnu Dharmottar Puran*, that the wall with this type of plaster could stand for nearly a century. This treatise also discussed the mixing of plant extracts for the first time together with the other materials to form a stable and strong plaster. An important turning point in the history of plasters came in the 7th century A.D where lime and sand were used for the first time for making the plaster. This plaster was used in the wall preparation of *Bagh* caves and is named as the plaster of *Bagh Style*. Amongst the new styles of plasters it is also worth mentioning the *Jaipur Style*; the plasters used in the 16th century in the state of Rajasthan. One come across these types of plaster for example at Amer Fort and other palaces in Rajasthan. Other examples of relevance are; the Shekhawati and the ancient temple of Gopinath at Parshurampur in Rajasthan (1743 A.D). Chamba Style plaster found at the Rangmahal is of very special type. It had a base of clay mixed with the organic materials. The detailed composition of these plasters are given in the Section 6.6.

6.2 Problems in Plasters Compilation

The plasters used in the ancient period were of very high quality and have given long life. This creates a demand for reproduction of those plasters. But there are problems in compilation and reproduction. The problem encountered in compilation is two-fold:-

1. Although it is possible to analyze the existing plasters from the historical places, but in the absence of historical literary data, these are difficult to reproduce as for example in the case of *Ajanta Style*.
2. There are cases of historical evidences in scriptures, but there is no physical presence of the plasters. There are diversified interpretations of the complex script which make it difficult to reproduce the plasters. A typical example depicting the variations in interpretation is cited below:

6.2.1 Variation in Interpretation of Ingredient [V. Singh, 1999]

Plasters of different styles have been interpreted by several scholars. There are remarkably different interpretations of the same ingredient done by different scholars of plaster in the *Vishnu Dharmottar Style*. Some of the examples are presented in the Table 6.1. These create difficulties in the reproduction of these plasters. The original composition of the plaster is given in *Sanskrit*. One of the example as is cited in the Table 6.1 is *Kshiren, Chir*, which is the water left over after extraction of cheese. This has been interpreted as plain water or milk. There is a vast difference between the water left over the cheese and plain water or milk. It is one of the example, likewise there are many more. This causes difficulties in the reproduction as the ingredients becomes different than those used originally.

6.3 Some Salient Features of Good Plaster

Before going into the details and discussing the compositions of plasters used it is appropriate to understand the properties of good plaster. A good plaster should have following properties:-

1. Moderate strength, easily attainable.
2. It should not produce defects such as *cracking* and “*pitting*” or “*popping*”.
3. It should have good plasticity and easy to work with.

6.3.1 Cracking of Plaster

Cracks of different types are often seen. Large gaping cracks, generally running from corner to corner of a room, or from a corner of a door or window, are probably settlement cracks. These occur due to the movements of the building after the plaster is set, and not necessarily due to any defects in the plaster itself. “Pointing up” after the building has found its level repairs these. Another type is a network of fine cracks, going through the plaster and forming maps on the surface. These may result from the insufficient bond between consecutive coats of plaster. Uneven expansion and contraction of the surface coating and the underlayers produce these cracks. Small, fine, superficial cracks over limited areas are produced by shrinkage, whilst drying. Lime contracts considerably during drying. This is counteracted in plaster and mortars by the addition of sand, and in a finishing coat by the addition, in many cases, of quick setting material such as calcined gypsum (plaster of Paris). It sets before the lime has had time to dry and shrink much.

Table 6.1 : Interpretations of the Same Ingredient given in Different References.

<i>Shri Vishnu Dharmottar Kshemraj Shri Krishnadas</i>	<i>Murankam</i>	<i>Madhukam</i>	<i>Sudhaashtaya</i>	<i>Kshiren</i>
<i>The Vishnu Dharmottar</i> Dr. Stella Kramirsch	<i>Mudga</i>	Rice liquor	Burnt Yellow Myrobalan	Water
<i>Vastu Shastra Vol.II</i> Dr. D.N. Shukla	<i>Mudga</i>	Rice liquor	Burnt Yellow Myrobalan	Water
<i>Chitrasutra of the Vishnudharmottar</i> Dr.C. Sivammurti	<i>Kundara grass</i>	Honey	Lime	Milk
Dr.V. S. Agarwal	<i>Paharikhra Loha(iron)</i>	-	-	-
Experimentation on <i>Shri Vishnudharmottar</i>	<i>Dekchun</i> (cast iron dust)	Mahua Flower	Lime	Milk

In the first column, the name of the book is given followed by the name of the author. In the following columns the ingredients are given.

Their nature and manner of occurrence can therefore generally determine the cause of cracks. They are due either to the movement of the building, to the use of a badly proportioned finishing coat, or to insufficient or ill-timed trowelling of the finishing coat. Small shrinkage cracks are effectively concealed by papering, and are then relatively harmless.

6.3.2 Pitting of Plaster

Sometimes it is observed that in a plaster, which is apparently free from any defect and which has been in position for times ranging from months to years, small conical pits suddenly appear. Investigations with test panels made up with plasters to which various impurities had been added have shown that this pitting or popping is due to expansion of particles of certain impurities in the lime, through slow slaking long after the main portion of the lime is set and hardened. The resulting bursting stress on the hardened plaster surrounding the particle finally releases itself almost explosively, blowing out a small crater in the surface. The offending particle can sometimes be noted at the bottom of the crater. Particles of overburnt lime, iron pyrites, and the products resulting from burning at a high temperature of limes containing clay, iron oxide and silica, are found to produce this effect. This not necessarily comes from lime; it can also come from sand. A distinction may perhaps be drawn between the pitting that shows a dark particle at the bottom of the pit, which is probably due to overburnt or semi-fluxed lime; and that in which a light particle appears, is merely due to unskilful slaking.

6.3.3 Lumps of Lime

Lime lumps are generally encountered in ancient mortars or it can be said that the ancient plasters and mortars are characterized by the presence of lime lumps. These are possibly produced by unslaked or weakly burnt lime or from the lime, which had already hardened prior to use. In general these lime lumps act as aggregates. No such lumps are found in modern lime plasters and mortars made from industrial burnt and slaked lime. This may be because the lime burnt in modern kilns is calcined to greater degree in comparison to the ancient lime where the degree of calcination is not uniform (see *burning of lime* Chapter 1.2).

6.3.4 Plasticity

Plasticity, from the plaster's standpoint is a difficult property to define. A formal definition of plasticity is "A property of solids in virtue of which they hold their shape permanently under the action of small shearing stresses, but they are readily deformed, worked or molded, under somewhat larger stresses". "Plasticity is thus a complex property, made up of two independent factors, which must be evaluated separately "[Bingham, 1922].

Emley [1920] has pointed out that there is still another factor, which affects ease of working, and which must therefore be considered in a definition of practical plasticity; it is water retention capacity of the plaster, and the consequent prevention of drying out by the "suction" of a partially dry plaster, masonry, or similar surface on which the plaster is being applied, and which tend to absorb by capillarity into its own pores the water which is an essential part of the plaster mixture. A plaster which is rather "soft" but which is very tenacious of its essential water-content will spread farther on a porous thirsty surface than a material initially softer and more "plastic", but rapidly loses its water and becomes thereby dry and friable. Well-matured slaked lime has this property of water retention developed to a high degree. This works successfully where the other plastering materials fail.

6.3.5 Drying of Plasters

Rate of drying of plaster affects both the immediate inhabitability of a building and the durability. Too rapid drying may cause failure. This is the case when plaster is applied in hot weather and not proper precautions are taken; like covering the plasters with wet cloth etc.

The preliminary hardening of the plaster takes place, quite rapidly, by the loss of water through the "suction" of the surface on which it has been applied and through evaporation; during this period spontaneous setting of putty mass occurs. Following this, the loss of water due to evaporation becomes more gradual; and there is a subsequent partial and superficial carbonation by atmospheric carbon dioxide.

The water added to a plaster is during mixing is merely for the purpose of rendering it plastic. Once the plaster is on the place this water has to be removed, but not so quickly and violently as to cause sudden volume changes, i.e. sudden shrinkage or powdering.

Another, though less important, point is carbonation of lime. Various investigators have observed that little absorption of atmospheric carbon dioxide takes place until plaster is fairly dry in the first instance, but not

completely dry. Burchartz [1912] has found that this process of carbonation is actually greatly accelerated by subsequent periodic wetting of the mortar. When plaster is completely dried out very rapidly the conditions are unfavourable for a subsequent carbonation. As a consequence a little strength will develop.

Accordingly, the drying should be moderately slow and general, and any intense local drying should be avoided.

With gypsum plasters; including the various proprietary plasters consisting essentially of calcined gypsum; even greater care must be taken not to remove the water too hastily, since, as a portion of this water is necessary for the chemical process of setting, the material may become friable and disintegrate far worse than a lime plaster would if dried prematurely under similar circumstances. Equal care should be taken with plaster material prepared by gauging lime putty with considerable proportion of some gypsum plaster, for the finishing coat. Particularly when this is applied over a well dried undercoat; since the bond will often be found to have failed completely after a short period if the drying out has been hastened unduly by the use of artificial heat.

6.4 Preparation of Plaster

Apart from the composition and the quality of lime the ancients laid great stress on the method of preparation of plaster. The main aim was to produce well homogenized plaster. Plasters were mixed aided with beating. Beating was done with wooden clubs. This produced well mixed and compacted plaster. Further this type of mixing ensured that any unslaked lime particles still present would be slaked. The mortar was usually thick and had short consistency, which reduces shrinkage whilst drying. This treatment may well lie behind the homogeneous nature and good workability of ancient plasters.

The regular beating and chopping up of the mixed plaster so frequently will evidently have the effect of promoting the deflocculation or dispersive process in the slaked lime with a resulting gain in the plasticity.

In the ancient renderings the surface was compressed and polished with great care. This produces a very fine meshwork on the surface [Malinowski, 1982]. It will influence the drying rate of the underlayers [Albrecht, 1965].

Literature about the mixing of mortars and the method of rendering is scarce. Very few recommendations exist in the literature. These do not go through much light on the details except that careful mixing is to be done. Early mortars exhibit splendid properties which is attributed to thorough

mixing and beating and not to the special lime compositions or to the secrets pertaining to the slaking of lime.

The ancients emphasized on the beating of plaster before use for tempering this when used in fine plastering. It has been suggested that the modern plasters have less durability than the ancient examples as a result of omitting this treatment. This omission appears to be due to the economic reasons.

6.5 Application Technique

The basic requirement of plasters applied on the stones, bricks or masonry is its good adhesion. This cannot be obtained by applying a thick layer of plaster directly on the surface of stone at a time. It will not hold, or may produce problems at later stage during drying. To avoid this, plasters are applied in several coats. In principle each coat should be allowed to dry before the application of next coat. The second coat should be applied whilst the first coat is still moist, but firm enough to resist the force applied. During drying carbonation also takes place which helps in giving strength to the surface.

6.5.1 Various Stages of Plasters

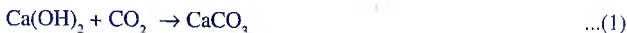
Here it is seen that first a coarse plaster is used, followed by the finer plasters. By so doing the pore structure gradually passes from coarse to fine pore system. Apart from the grading of the plasters, the plasters were applied in a specific manner. These were applied in different steps; first a ground coat was applied. When this is dried enough and acquire some strength the second coat is applied, when this coat becomes dried enough, and acquire some strength the third coat is applied. The process repeats till the final coat is applied and the surface is polished. Now what happens when the plasters are applied in steps is described below:-

When the plaster dries, water evaporates from the surface, water to binder ratio decreases, Carbon di-oxide from the atmosphere interacts with the calcium hydroxide on the surface of the plaster producing calcium carbonate (Figure 6.1 and Figure 6.2). By both these processes the plaster hardens and gets strength. This enables the first coat to hold the second coat of plaster.

When the second coat is applied, some of the liquid, which is mostly calcium hydroxide from the plaster is soaked by the first coat as it is drier than the plaster applied. The contact is between semi dry and wet surface instead of wet to wet surface if the plaster is applied on the wet surface.

This provides a continuity of the binder between the first and the second coating. Apart from this, because of the loosening of the binder, the strength of the plaster adjacent to the first coat becomes low, whereas the strength of the plaster on the surface of the first coat becomes high.

The carbonation process is not that simple as explained earlier. It is complicated and takes place in steps. It is shown by the schematic diagrams 6.1a, 6.1b, 6.2a, and 6.2b. The reaction takes place according to the eqs.1-4.



Stage 1: During drying, water evaporates and the relative humidity decreases, carbon dioxide, CO_2 , from the atmosphere enters the pore water, forms carbonic acid, which interacts and forms calcium bi-carbonate, $\text{Ca(HCO}_3)_2$. This interacts with calcium hydroxide and forms calcium carbonate, CaCO_3 . It is shown in the Figure 6.1(a) and Figure 6.1(b). Thus the calcium hydroxide layer is followed by calcium bicarbonate, calcium carbonate and calcium bicarbonate (Eqs. 1, 2 and 3).

Stage 2: When the second coat is applied, calcium bicarbonate reacts with it and forms calcium carbonate (Eq. 4). Thus the calcium hydroxide layer is followed by calcium carbonate, calcium bicarbonate and calcium hydroxide. This is illustrated in the Figure 6.2a and 6.2b.

Thus for carbonation to occur, carbon dioxide should get dissolved. When the pores are filled up with water, (plaster is wet), there is no place for carbon dioxide to enter, carbonation becomes very slow, and consequently the plaster hardens very slowly. Similarly when the humidity is very low <25%, there is no water for carbon dioxide to get dissolved, and carbonation becomes very slow. It is seen that the carbonation is maximum when the RH is between 55-75% [Ashan, 1985]. It is therefore very important that the plaster should be dried enough before the second coat is applied.

This makes a good bonding between the two plaster coatings, and the surface contact of the coatings work like grids. Because of the successive decrease in the strength, the delaminations will decrease and the second coat will not shear off. Besides, in case of damage the whole plaster will not shear off. This will also reduce the shrinkage and cracks, which use to occur otherwise.

The carbonation can also occur when the plaster is hard. In this case calcium carbonate gets dissolved and recrystallizes. It is often seen in the old plasters and concretes. By re-crystallization the crystals of calcium carbonate formed are much bigger and are much stable. One such recrystallized calcium carbonate is shown in the Figure 6.2c.

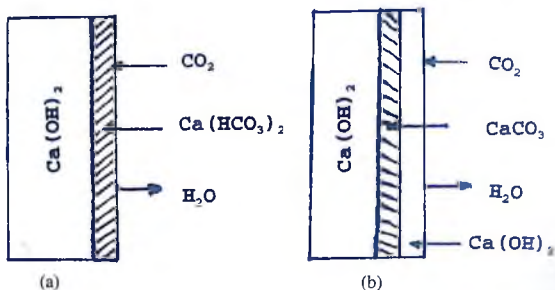


Figure 6.1 : Schematic diagram showing the process of drying and simultaneous carbonation, Stage 1, (a) formation of calcium bicarbonate, (b) formation of calcium carbonate.

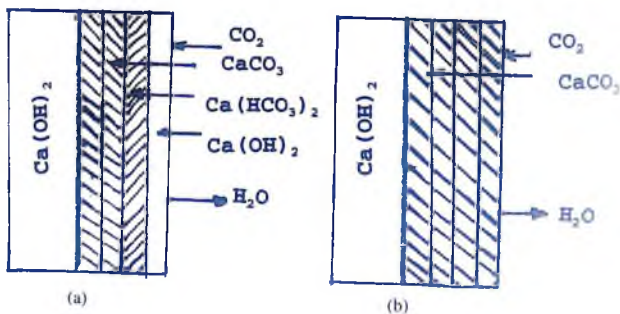


Figure 6.2 : Schematic diagram showing the process of drying and simultaneous carbonation, Stage 2, (a) formation of calcium carbonate, (b) formation of calcium bicarbonate.

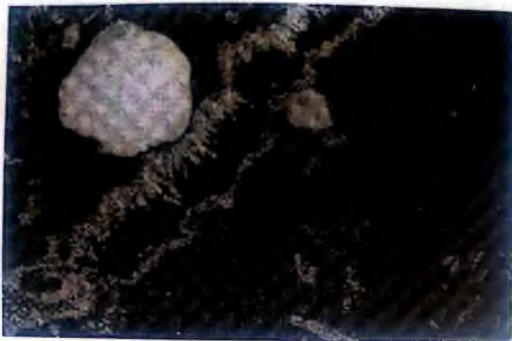


Figure 6.2c : *Rycrystallised calcium carbonate crystal [Thorborg von konov, 1985].*

The first rendering coat is composed of “coarse material” i.e, sand, lime and when on lath; hairs. The plaster is applied with fair amount of pressure, so as to make a good bond with brick or other masonry surface. In doubled-up work, a second coat of coarse material is applied immediately and made plane by use of the “rule”, “derby” and “float”. In a three-coat work the “floating coat” is applied over the scratched now dry first coat. The finishing coat or “setting coat” of “fine material” is applied in a thin layer over the floating coat when the latter is dry and can be omitted altogether in less exacting work. Its function is principally ornamental. An extremely high plasticity, and a regulated time of setting, are essential in the material used for this final coat: It has become a customary therefore to combine in “fine stuff” the high plasticity of a fat lime putty with the quick-setting power of calcined gypsum (plaster of Paris), by gauging the putty with a variable amount of latter; and a number of quick-setting substitutes for lime plaster have also come into use. Sand is frequently omitted in this setting coat, and it is to be noted that the ancients used marble dust here. Owing to the absence of sand, and in order to avoid shrinkage-cracks, the coat has to be consolidated by trawling the surface whilst still just short of setting; as this is quite a critical matter, considerable experience and skill are required of the craftsman to judge exactly the right moment and to use the wet brush and trowel in precisely the right manner to achieve the desired result. Different types of finish can be imparted at this stage by varying the procedure.

Here it is seen that first a coarse plaster is applied followed by finer plaster. By so doing, the pore structure gradually passes from coarse to fine pore system. This makes easy transport of moisture from under layers and thus helps in study drying. This decreases the differentials in the under layers which occur otherwise due to the uneven moisture balance. This diminishes the stress and strain in the under layer and consequently increases the durability properties.

This is a general idea about different coats of plasters. Plastering for special purposes is much more complicated and is accomplished in many stages. Plasters done on the walls for painting which is done in 30 stages is described in *Section 6.5*. Surfaces of some of the plasters done according to different styles are shown photographically in *Section 6.6*.

6.5.2 Restoration of Asafi Immambara "*Bada Immambara*" at Lucknow

A typical example of different types and stages of plaster is seen in the restoration of *Asafi Imambara* at Lucknow (Figure. 6.3). It is raised by Nawab Asaf-ud- Daulla in the late 1770s. There are rows of doorways on the 3rd floor. These are damaged and the restoration work is done by the Archaeological Survey of India, Lucknow circle.



Figure 6.3 : Outside view of the Asafi Imambara [Photo, Chandra, 2000].



Figure 6.4 : Physical appearance of the damaged doorways [Photo, Chandra 2000].



Figure 6.5 : Close up photograph of the pillar showing 4 coats of plasters over the red bricks base [Photo, Chandra, 2000].



Figure 6.6 : Close up photograph showing details of the damage of doorway [Photo, Chandra 2000].



Figure 6.7 : Preparation of the plaster for restoration [Photo Chandra 2000].



Figure 6.8 : Mason repairing the pillar [Photo, Chandra 2000].

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Figure 6.9 : Repaired doorways [Photo, Chandra, 2000].

The author happens to be there during restoration in November 2000. The work done is described here together with the photographs. The damaged condition of the doorways is shown in the Figure 6.4. A close up photograph (Figure 6.5) elaborates the condition of one of the pillars of the doorway after cleaning. There are 4 coats of plaster over the red bricks frame of the pillar which were joined by red lime mortar. Figure 6.6 shows the physical appearance more closely.

The restoration work was done using the plasters close to those used in the ancient period. The work was done in different steps:

- The doorways were cleaned.
- These were wet with water.
- A coat of coarse mortar was laid over the wet brick surface, and it was left to dry.
- When it was sufficiently dried, second coat of finer plaster is laid over the first coat, and left for drying.
- When the second coat dried enough, third coat is applied, and is left for drying.
- Finally very final plaster is applied as the final coat and the surface is smoothened.

The material used for making the plaster was red lime, coarse sand “*Maurang*”, fine river sand, jaggery and iron oxide. Water is added to the dry mix of the ingredienses according to the guidance of the able mason and is mixed by hand. The mortar is seen in a tray over a bucket in Figure 6.7 and the mason sitting and working with the plaster in the Figure 6.8. Figure 6.9 shows the restored doorways. These look identical to the original both in colour and finish. Here it should be noted that the work done is slowly but has perfection. It shows that still the old principle is followed “Quality production” and not considering the time factor involved in accomplishing the work. It is very important aspect.

6.6 Some Typical Plaster Compositions

The work done by late Mr. Munni Singh of National Laboratory for Conservation of Cultural Property, Lucknow, India, in this area is significant. In the past 25 years he has tried and reproduced several styles of ancient plasters (almost 30 in number with work on more in progress). After his death his son Venkat Singh and his wife Madhuri Singh are continuing this work under the enterprize named DHOROHAR at Lucknow.

U.P., India. They have participated in an exhibition "Golden Eye" organized by Rajeev Sethi in New York [1985] where four styles of plasters have been exhibited. Most of the information in this chapter specifically on the plaster composition is based on the materials given by Mr. Muni Singh and Mr. Venkat Singh [1999].

Some important styles of plasters which represent an entire gamut of the development in the area of plasters from the earliest *Vinay Pitak to Bhukshas* are given here. Vinay Pitak has four sections; a) *Patimokha*, b) *Sutta Vibhanga*, c) *Kandahakas*, and, d) *Parivara*. It is sub-divided into *Mahavaga and Chullavagga*. Plasters are described in *Chullavagga* which deals with the life of the Bhikkhus, their residence, furniture etc., [Majumdar, 1950]. It is tried to illustrate the plasters in layer wise sections with clear indications of the materials used in each layer.

The various styles that have emerged are the outcome of different objectives in mind of the creators as to what the plaster is targeted to achieve. In this conjunction it would be pertinent to note the following features of the plasters:-

1. The plaster on the wall that becomes a protective layer serves as ritual ornamentation.
2. The plaster on the wall that is textured to provide strength and pattern.
3. The plaster on the wall that becomes a relief to express ritual belief.
4. The plaster to cover different surfaces and utilities like storage. *Choolas* (A place for making fire to make food inside the house) etc.
5. The plaster on perforated structures that are inlet of light (openings. *Jalies* etc).

The compositions, which are given here contain comprehensive information about the construction; such as support, type of plaster, ingredients of plaster, wall sections, relief work, floor etc. Ingredients mentioned in the composition are of inorganic and organic origin. Their functions are described in the Chapter 1; "Binders" and in the Chapter 4 "Natural Polymer". Briefly, it can be mentioned here that the organic materials used were natural agro-products and were added to enhance the durability properties.

6.6.1 Vinay Pitak (I)

Period	3rd Century B.C
Edited by	Majumdar, R.C
Support	Brick
Plaster	Mud Plaster
Ingredients	Clay, Cow dung, and ash
Wall sections	Four Sections; Support, Coarse plaster, Fine plaster, and grout
Floor	Mud
Relief work	No

6.6.2 Vinay Pitak (II)

Period	3rd Century B.C
Edited by	Majumdar, R.C
Support	Bricks
Plaster	Mud Plaster
Ingredients	Mustard cake, Clay, Bee-wax, and o
Wall sections	Four Sections; Support, Coarse plaster, Fine plaster, and grout
Floor	Mud
Relief work	No

6.6.3 Vinay Pitak (III)

Period	3rd Century B.C
Edited by	Majumdar, R.C
Support	Bricks
Plaster	Mud Plaster
Ingredients	Clay, Rice husk
Wall sections	Four Sections; Support, Coarse plaster, Fine plaster, and grout
Floor	Mud
Relief work	No

6.6.4 Vishnudharmottar Purana

Period	4th-5th Century A.D
Written by	Kshemraj Shri Krishnadas
Support	Stones
Plaster	Brick powder and mud
Ingredients	Brick powder, clay, Balsamodendron (Guggul), Bees-wax, Flower of Bassia latifolia (<i>Mahua</i>), Cast iron, Jaggery, Oil of saaf flower (<i>kusum</i>), Lime, Aegle's pulp (<i>Belgiri</i>), Bark of Ficus, Whittiana (<i>Pakar</i>), Bark of <i>Neem</i> , Milk, Resin of <i>Sal</i> tree, Chalk,
Wall sections	Four Sections; Support, Coarse plaster, Fine plaster, and grout
Floor	No
Relief work	No

6.6.5 Ajanta Style

Period	2nd Century B.C to 6th Century A.D
Support	Volcanic trap rock or basalt, surface of the carrier is rough and uneven with furrows and chisel marks.
Plaster	Mud plaster
Ingredients	Mud, Cow dung, Rice husk, Stone powder, Lime, <i>Kodo husk</i> , kidney bean, jaggery.
Wall sections	Four Sections; Support, Coarse plaster, Fine plaster, and grout
Floor	No
Relief work	No

6.6.6 Bagh Style

Period	Early 7th Century A.D
Support	Stone
Plaster	Lime plaster
Ingredients	Lime, Red clay, Gravel, Hemp's fiber.
Wall sections	Four Sections; Support, Coarse plaster, Fine plaster, and grout
Floor	No
Relief work	No

6.6.7 Samarangana Sutradharna

Period	10th Century A.D
Written by	King Bhoja
Support	Stones
Plaster	Mud plaster
Ingredients	Sand, clay, juice of <i>Euphorbia antiquorum</i> (<i>Cactus</i>), <i>Chenopodium album</i> (<i>Bathua</i>), <i>Benineasa-Cerifera</i> (<i>Petha</i>), Juice of <i>Toddaliquleate</i> (<i>Kharmarjri</i>), <i>Archyranthes aspera</i> (<i>Chachira</i>), Sugar cane extract, Milk of cow, <i>Dalbegiasisso</i> (<i>Fruit of Shisham</i>), <i>Solanum indicum</i> (<i>Bhatkattaya</i>), <i>Terminalia agoum</i> (<i>Fruit of Arjun</i>), <i>Melia Indica</i> (<i>Fruit of Neem</i>), <i>Cassia Testula</i> (<i>Amaltas</i>), Sea salt, Pulse of <i>Phaseolus</i> (<i>Urad ki daal</i>), Flowers of <i>Salmalia malabarica</i> (<i>Shehmal</i>), Pulp of <i>Aegle matmelos</i> (<i>Belgiri fruit</i>).
Wall sections	Four Sections; Support, Coarse plaster, Fine plaster, and grout
Floor	No
Relief work	No

6.6.8 Apparajita Praccha

Period	11th Century A.D
Written by	Shri Bhuwan Dev
Support	Stones
Plaster	Mud plaster
Ingredients	Chalk, Red ochre (<i>Geru</i>), Yellow ochre (<i>Ramraj</i>), Linnseed (<i>Alsi</i>). Flour of Barley (<i>Jau</i>), Wheat flour. Milk of <i>Calotropis gigantea</i> , Bark of <i>Ficus wightrana</i> (<i>Pakar</i>), <i>Mimosops elengi</i> , Milk of cow, Jaggery, <i>Solanum indicum</i> (<i>Bhatkattaya</i>), Oil, <i>Ghee</i> from cow milk.

Wall sections

Four Sections; Support, Coarse plaster, Fine plaster, and grout
No

Relief work

6.6.9 Abhilashitartha Chintamani

Period

12th Century A.D

Written by

King Someswara

Support

Stones

Plaster

Lime plaster

Ingredients

Chalk, powder of conch shell, gur and glue.

Wall sections

Four Sections; Support, Coarse plaster, Fine plaster, and grout

Floor

No

Relief work

No

6.6.10 Silparatna

Period

16th Century A.D

Written by

Shri Kumara

Support

Stones

Plaster

Lime plaster

Ingredients

Lime from conch shell, Ripe banana, sand, Cashew nut milk (a type of dry fruit), Kidney bean, Jaggery.

Wall sections

Four Sections; Support, Coarse plaster, Fine plaster, and grout

Floor

No

Relief work

No

6.6.11 Jaipur Style

Period

16th Century A.D

Support

Stone

Plaster

Lime and marble chips plaster

Ingredients

Lime, Marble chips, Fine marble chips, Marble powder, Milk, Guggul, Curd, Jaggery

Wall sections

Five Sections with support, *Sareshi*, Plaster, Ground layer and surface layer

Floor	Same material
Relief work	No

6.6.12 Chamba Style

Period	Late 16th Century A.D
Support	(a) Stone rubble and mud enclosed in wooden battens. (b) Thin bricks
Plaster	Mud plaster
Ingredients	Clay, Lime, Sand, and Fibers
Wall sections	Four sections; Support, Coarse plaster, Fine plaster, and grout
Floor	Stones
Relief work	No

6.6.13 Traditional Mud Plaster Type I (Bhukksa Tribe, U.P., Terai)

Period	20th Century A.D
Support	Bamboo and grass
Plaster	Mud plaster
Ingredients	Mud, Straw, Cow dung
Wall sections	Four sections; Support, Coarse plaster, Fine plaster, and relief work
Floor	Mud
Relief work	Yes

6.7 Vajralep (Stonehard Plaster), an Unique Plaster

In the construction of temples and buildings it is necessary to join the wood, bricks and stones. In ancient time different materials have been used for this purpose. For joining the wood; iron, mud bricks; mortar of mud, and for joining the burnt bricks and stones special plasters (*Vajralep*) had been used. While the main purpose of these plasters was to join the bricks and stones, these were also used for plastering the walls. These were made of ingredients chosen to produce the plasters, which will be durable in the environmental conditions to which these will be exposed. These are mentioned in the Indian mythological books; *Shilpratna*, *Mansoullas* and *Abhilashitarth Chintamani*, and *Vishnudharmottar Puran* (Chapter 40).

Durable high quality plasters were made by mixing the organics in the mud, mud-lime mixture together with the sand, small crushed pieces of the burnt clay or burnt brick and stones. This was further strengthened by using the fibers from coconut, cotton (*Kapas*), stems of cereals (*Bhusa*), and coarse part of the cereals (*Choker*). The old plasters made with the addition of different types of organic were durable and was the secret behind their high durability. The art of old plasters was in the selection of materials especially the organics, method of their preparation and the application technic. After careful study of the organic materials used in making *VAJRALEP*, these are divided in three groups.

6.7.1 Division of Organics used in *Vajralep*

The natural polymers used in making *Vajralep* are divided in three main groups according to their specific composition and characteristic properties:

1. Material containing fruit pulp which gets hard when dried-(for hardness).
2. Material producing gum (for adhesion).
3. Fibrous material (for reinforcement).

In the first group comes the products, which are for making hard, smooth and good looking plaster. These products are for example: *Kaitha and Belgiri fruit pulp, Linseed and Urad Ki Dal, Lac, Mahua*, powder of cattle-horn, cow-dung, *Neem* seeds, tin, glass, brass, flour and "*Chokar*" coarse part of cereals.

In the second group comes specially the products which have adhesion characteristic. These are; *Bel fruit, seeds of salie, gum from Deodar, gum of Shreewasak, Gum of Sankhua, lac* etc.

In the third group comes fibrous products such as; cotton flowers *Kappas, Semal ke phool*, coconut fibers, bark of *Dhanwan and Vach trees*, smoke web, skin of cattles etc.

It is difficult to strictly group the above products as many of them posses two or more properties. For example *Urad Ki Dal* and linseed get hard when dried like the materials in group 1, and gum producing material like in the group 2. *Mahua* flowers also possess the properties mentioned in 1 & 2. Coarse part of flour, flour, tin, glass, lead are also used for making plaster. Lac has the properties of all three. The plaster which is produced with the addition of the specific materials in the specified proportion becomes smooth, hard, plane, homogeneous and long lasting. Considering the high strength of the product the *Granthkar* (writers of the mythological books) mention the life span of these products as 1000's of years.

6.7.2 Types of Vajralep

In *Vishnudharmottar*, 4 types of Vajraleps are described;

1. *Kalk samanya lep* (ordinary plaster).
2. *Vajralep*.
3. *Vajralep* for floor.
4. *Vajrametal-lep*.

In *Vishnudharmottar Puran* and other ancient mythological books all these plasters are named as *Vajralep*. Out of these *Kalk samanyalep* was ordinary plaster and was most commonly used.

Method of Preparation

For making Vajralep first of all a solution is prepared by boiling some substances in water. The substances used and the method of preparation of these mortars is described here.

1. **Ordinary Plaster (Samanyalep):** This use to be the basic solution. In a pint of water (according to the amount of substances used and subject to the experience) dry fruits of *Tendu* and *Kaitha*, flowers of *Semal*, seeds of *Salai*, Skin of *Dhanvaj* and *Vach-tree* are mixed and cooked over fire. When one eight part of the solution was left gum from *Saral-tree*, *Gugul*, *Bhilawa*, *Deodar-tree* gum, gum of *Sankhua*, linseed, pulp of *bel* fruit etc were crushed, made into a paste and were mixed with the water cooked solution. The amount of these materials depended upon the service conditions to which the plaster is going to be exposed and was decided by the wise mason.
2. **Vajralep:** The solution made here is by the same procedure as is mentioned in 1. Only a few other type of substances are used. These are lac, smoke-web from the house, fruit of *Nagbala*, *Mahua* flowers, *Majidh rual*, *Anvala*, and *Sarj*.
3. **Vajratal Lep:** In the solution prepared by the procedure mentioned before, powder of cattle and goat horns, hairs of donkey, glue obtained by boiling the cattle skin, cow-dung, seeds of *Neem* are mixed and third type of *Vajratal lep* is prepared. Juice of *Neem* and *Kaitha* are also used in this plaster.
4. **Vajrasanthal Lep:** In the ground plaster mentioned in 1, some metals are mixed additionally and very extraordinary *Vajralep* is prepared. According to *Vishnudharmottar Puran* (Indian mythological book), eight portion of tin or glass, two parts *Kansa* and one part *Riti*

(rust of iron) were mixed. In other *Granth (Vrahatsangrhit)* eight part glass, two parts of lead "*Kansa*" and one part brass mixing is mentioned.

6.7.3 Application of *Vajralep*

According to *Vrahatsangrita*, warm *Vajralep* if used on the temples, roofs, *Shivling*, *Images of God*, *Bhittiyon* and on the surface of the wells its life is expected to be thousands of year. In the other vedic inscripts, it is mentioned that some type of *Vajralep* prepared according to the methods mentioned above must be used over the buildings constructed of the burnt bricks, and made of stones. By so doing the building attains high strength and becomes durable for thousands of year. To get a pleasant look lime wash is done over *Vajralep*.

In the plasters mentioned in the mythological books, the major part is of mud, therefore these mortars served the purpose more of making the surface plain than making it very hard. For making these in the mixture of mud and lime, *flowers of Semal*, *Mahua*, *Urad ki Daal*, and the *juice of Trifla* are to be added. Besides this, fibers of coconut and cotton, coarse part of flours, sand, small pieces of burnt crushed bricks, and stones are to be mixed.

These plasters were made and used successfully for ages. The ancient builders did not make them all of a sudden and just by chance, they had appropriate knowledge and understanding of the materials property. Besides they have tested very carefully the materials. In this way they acquired the knowledge by trials and error. Those recipes became traditional so much so that even today it is a customary to use straw, cotton flowers (*Kappas*), *Methi*, *Urad KI Dal*, *Alsi (linseed)*, Raw sugar (*Gur*). Flour. Coarse part of flour (*Chuni, choker*), *Chota* and other materials which produce smoothness and provide adhesion. These natural materials are used in the plaster over the mud wall and in the materials used for making the roof over the houses made of bricks.

6.8 Plasters and the Techniques of Wall Preparation for Paintings

Preparation of the wall for painting is the deciding factor for the outcome and the durability of the painting. It is not an easy task and needs enormous experience and vision. It is a combination of art and science. Plasters used on the walls on which painting is to done consisted of very special material. In addition to the materials there was a specified technique for the

application. Plasters used on the walls of Ajanta caves, Sirgirea caves and Bagh caves are described here. Method of their application as is mentioned in *Vishnudharmottar* is also described. In addition to the plasters, the technique of producing different colours is also elaborated. One very seldom come across this type of detailed description about the colors tints and their production from different metals and other natural materials.

The plasters used in the wall preparation varied, may be due to the condition of the wall or due to the prevailing environmental conditions. It is seen from the composition of the plasters used of some of the caves:

6.8.1 Ajanta Caves

The plaster to be applied on the walls for preparation for painting consisted of clay, cow dung, stone powder, rice husk and lime.

6.8.2 Sirgirea Caves

The plaster to be applied on the walls of the caves consisted of tempered clay, kaolin, rice husk, coconut fibres and lime.

6.8.3 Bagh Caves

The plaster to be applied on the walls consisted of red clay, *Maurang*, lime and jute.

According to *Mansoullas* the plaster to be applied on the walls consisted of powder of Conch "*Shankh*", *Katha*, pulses (*Mung*, *Urad*), molasses, and boiled bananas.

6.8.4 Wall Preparation

The wall preparation for painting is complicated and time consuming. The method of applying stucco on the walls is described by Vitruvius [Vitruvius, 1960] and the method of wall preparation for painting is given in the book "*Vishnu-dharmotar*" written between 4th and 7th century. This preparation is done in 30 steps.

Stucco Work on the Walls (Vitruvius)

Stucco work on the walls is done in steps as is described by Vitruvius [1960]. Short description of this method is given below:

Step 1 : Set the vaultings in their places, apply the rendering coat to their lower surface; then lay on the sand mortar, and afterwards polish it off with powdered marble. After the vaulting have been polished the moldings are to be set directly beneath them. These obviously ought to be made extremely

slender and delicate. For when they are large, their weight carries them down, and they cannot support themselves.

Step 2 : Some moldings are flat, others in relief. In the rooms where there has to be a fire or a good many lights they should be flat, so that they can be wiped off more easily. In summer apartments and in exedrae, where there is no smoke nor soot to destroy them, they should be made in relief. However, soot and smoke can gather from other houses also.

Step 3 : Having finish the moldings, apply a very rough rendering coat to the walls, and afterwards, when the rendering coat gets pretty dry, spread upon it the layers of sand mortar, exactly adjusted in length to rule and line, in height to the plummet, and at the angles to the square. The stucco will thus present a faultless appearance for paintings. When it gets pretty dry, spread on a second coat and a third coat. The better the foundation of sand mortar that is laid on, the stronger and more durable in solidity will be the stucco.

Step 4 : When not less than three coats of sand mortar, besides the rendering coat, have been laid on, then, the mixture for the layers of powdered marble is made, the mortar being so tempered that when mixed, it does not stick to the trowel, but the iron comes out freely and clean from the mortar trough. After this powdered marble has been spread on gets dry, lay on a medium second coat. When that has been applied and well rubbed down, spread on a finer coat. The walls being thus rendered solid by three coats of sand mortar and as many of the marble, will not possibly liable to cracks or to other defects.

Step 5 : Walls thus prepared had solid foundation, and smoothness achieved by polishing and becomes hard and dazzling like white marble. This will bring out in splendor the colours, which are laid on at the same time with the polishing. These colours, when are laid on stucco still wet do not fade and are permanent.

Step 6 : Stucco that is properly made does not get rough with time, nor lose its colors when it is wiped off, unless they have been laid on with little care and after it is dry. So, when the stucco on walls is made as described above, it will have the strength and brilliancy that will last for long time. But when only one coat of sand mortar and one of fine marble have been spread on, its thin layer is easily cracked from want of strength, and from its lack of thickness it will not take on the brilliance, due to polishing, which it ought to have. By applying several coats in steps the delaminations which occur

due to shrinkage and drying are minimized. This is the main reason that the foundation of wall is faultfree and does not show cracks.

When the polish is done on a thin plate, it reflects indistinctly and with a feeble light, while one that is substantially made can take on a very high polish and reflects a brilliant and distinct image when one looks there in. Besides the quality and intensity of reflection, the polish done over the thin plates does not last for long time. It fades soon.

The polishing significantly improves the durability properties of plaster specially the differentials which are formed due to the variation in the temperature; causing expansion and shrinkage of the structure due to the difference in the behaviour of different materials used in making the concrete. Apart from this, It decreases the absorption property of concrete, which is the major source of concrete deterioration. It is discussed in the Chapter 11 in detail.

Stucco Work in the Damp Places

In the apartments which are level with the ground, apply a rendering coat of mortar, mixed with crushed burnt bricks instead of sand, to a height of about three feet above the floor, and then lay on the stucco so that those portions of it may not be damaged by the dampness.

In case wall is in a state of dampness all over, construct a second thin wall a little way from it on the inside, at a suitable distance, and in the place between two walls run a channel, at a lower level than that of the apartment, with vents to the open air. Similarly, when the wall is brought up to the top level. Leave air hole there. For if the moisture has no means of getting out by vents at the bottom and at the top, it will not fail to spread all over the new wall. This done, apply a rendering coat of mortar made with burnt brick to this wall, spread on the layer of stucco, and polish it.

In case there is not room enough for the construction of a wall, make channels with their vents extending to the open air. They lay two-foot tiles resting on the margin of the channel on one side, and on the other side construct a foundation of pillars for them, made of eight inch bricks, on top of each of which the edges of two tiles may be supported, each pillar being not more than a hands breadth distant from the wall. Then, above, set hooked tiles fastened to the wall from bottom to the top, carefully covering the inner sides of them with pitch so that they will reject moisture. Both at the bottom and at the top above the vaulting they should have air holes.

Then, whitewash them with lime and water so that they will not reject the rendering coat of burnt brick. For, as they dry from the loss of water burnt out in the kiln, they can neither take nor hold the rendering coat

unless lime has been applied beneath it to stick the two substances together, and make them unite. After spreading the rendering coat upon this, apply layers of burnt brick mortar instead of sand mortar, and finish up all the rest in the manner above for the stucco work.

Wall Preparation (Vishnudharmottara)

Wall preparation for painting is done in a very special way. It is accomplished in 30 steps and is described in Vishnu-dharmotar in details. A short description is given here.

Steps 1-3 : Brick powder of three varieties (fine, middling and coarse) should be mixed with clay, one third of it in proportion. To this is added fragrant of gum resin, molasses, *saff-flower* (*kusun* flower) soaked in oil; all in equal proportion. To these two parts already composed is added powder of lime (three fourth burned) with *belgiri fruit pulp* and lamp black. The rest or the remaining fourth part is an addition of sand (a little more or less according to the experience of the skilful artist).

Step 4 : Then it is soaked in water, stored in a pot so as to get bubricous and is kept so for a month.

Step 5 : When after a month, it becomes very soft paste, it has to be very carefully taken out and a coat is applied by the skilled artist on the wall after testing that the wall is quite dry.

Step 6 : The coating should be smooth, very fine, free from uneven patches neither too thick nor too thin.

Steps 7-8 : When the wall is dry after this coat and is still not quite smooth, it should be smoothened by an application of the clay bereft of *sarjarasa* and oil by coats of lamp black. Further the surface should be frequently wetted with milk and polished.

Step 9 : The wall dries very soon by so doing and does not perish after hundred years.

Step 10 : In this way a variety of mosaic floors can be made in picturesque fashion by the use of two or different colors.

Fixation of Painting

Steps 11-13 : When the wall is dry, on a good day, which is appropriate to the *Gana* (*Deva* in presence of *Marushya* and *Rakshas*), specially suited for starting the picture (like *Punarvasn* for *Rama*, *Rohini* for *Krishna*,

Mrigaria for Shiva etc...), the painter dressed in immaculate white, pure in mind and body, having adored *Vedic* seers and uttered auspicious hymns (*Svativakya*) and having bowed to the masters, facing to the east should start his work of painting.

Steps 14-15 : The wise artist should draw and fix up the proportions and positions of the figures. Then he should color the paintings with the colors appropriate in their different situations.

Step 16 : The Primary colours are five: white, yellow, red, black and blue, with many intermediate tones.

Step 17 : First the colour scheme is arrived at by separating them according to the artists knowledge and capacity for creating the atmosphere in the picture as there should be produced hundreds and thousands of colour tones.

Step 18 : Blue and yellow mixed produce green. It may be pale with greater medium of white or deeper blue.

Step 19 : According to the colours used quantitatively there is predominance of colour, lighter darker or in equal proportions - making it three fold.

Steps 20-21 : With one tone predominant many tints are produced. Thus there is the yellowish green from *durva* grass, light wood pale green, green like green peas and so on, all of them can be produced.

Steps 21-23 : Blue mixed with white is a tertiary colour which again is manifold by predominance diminution's equal or less proportions of one or the other. Thus is formed the tint like that of the blue lily.

Steps 23-24 : Beautiful tints are produced by mixing in calculated proportions. Red *laksha* tin mixed with white like the *lodhra* flower become red like red lotus, a colour so charming. This again produces several other varying tints.

Steps 25-26 : The materials for colours are gold, silver, copper, mica, lapis lazuli, red lead, red lac, vermilion, indigo and several more.

Step 27 : Metal colours are to be laid delicately in thin sheets or by liquefying them by chemical methods.

Step 28 : Mica becomes the solvent liquefier when added to iron. Thus when metal colouring is to be done, they have to be suitably prepared.

Step 29 : The liquefier for mica is mercury. Hide glue and *bakula* resin glue act to fix and strengthen colours. Vermilion Juice is also used for this.

Step 30 : The picture is painted with brushes of high quality hairs and with the colors strengthened by the glue of elephant hide, the juice of durva and bark resins cannot be destroyed even though washed with water. This has prolonged life.

It is seen here that the wall preparation for making the paintings is quite sophisticated and time consuming. But once the plaster is made as is described and is applied in the prescribed manner it will stand for very long time. This is one of the major difference in the old period and the today. In the old period time was no criteria but quality was in demand, whereas today there is not so much time, all the projects are to be finished within the stipulated time which is not enough for making this type of plasters. Here one has to find out the quickest way of producing the concrete, and then there is a risk of long time durability properties which are not very often tested. If one compares the cost incurred in making a construction taking longer time with enhanced durability properties with the one made today plus the maintenance cost involved due to the repair work needed owing to its lower durability, it will be cheaper to construct using the first procedure. Besides this, it will escape the public inconvenience caused during the repairs.

6.9 Examples of Various Stages of Plasters

Plasters used in different “styles” varied in composition and their application technique. These were laid in several stages. The technique of laying the plaster in each stage was very specific. To give an idea, the look of some of the plasters are shown photographically in the Figures 6.10-6.13. These plasters were laid in four stages. Figure 6.10 shows stage 1-4 of the plaster with composition mentioned in the *Vishnudharmottara Purana*; section 6.6.4. Figure 6.11 shows four stages of plaster according to the composition of *Bagh style*, section 6.6.6. Figure 6.12 shows four stages of plaster of the composition mentioned in *Samaranga Sutradhara*, section 6.6.7. Figure 6.13 shows four stages of plaster as is described in *Silpratna*, section 6.6.10. Figure 6.14 shows the relief work of the traditional mud plaster type one used during *Bhuksa* tribes during 20th century as is described in section 6.6.13.

A detailed construction showing different materials and their thickness is shown by a cross section in the Figure 6.15. This type of construction is done at Shekhawati; Gopinath temple, *Parushurampur, Rajasthan*.

The wall is made of grey stone with *Surkhi* (a pozzolanic material); milled red brick powder and lime as mortar. The thickness of the wall is

85cm. The following 8mm layer is of *Sareshi* containing Jaggery. Next is 15mm coarse plaster, 12mm fine plaster, 6mm *Sandla or Loi*, 2mm *kada* of lime and finally 2mm thick layer of color.



Figure 6.10 : Vishnudharmottara Purana; Various stages of plaster [Photo, Venkat Singh, Lucknow, India].



Figure 6.11 : Bagh Style; Various Stages of Plaster [Photo, Venkat Singh, Lucknow, India].

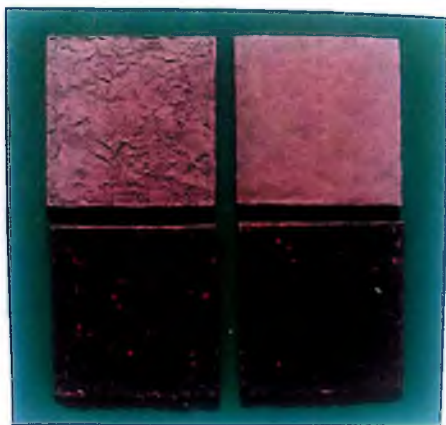


Figure 6.12 : Samrangana Sutradhara, Various stages of plaster [Photo, Venkat Singh, Lucknow, India].



Figure 6.13 : Silparatna; Various stages of plaster,[Photo, Venkat Singh, Lucknow, India].



Figure 6.14 : Relief work of Bhuxsa Tribes, mud plaster; [Photo, Venkat Singh, Lucknow, India].



Figure 6.15 : A cross section showing the materials and their thickness Shekhawati (Gopinath Temple, Parshurampur), [Venkat Singh, Lucknow, India].

Here, it is seen (Figure 6.15) that the plaster is applied on the wall gradually, varying in grade from coarse to fine, and not abruptly from coarse to fine. By so doing the structure attains a very systematic and gradual distribution of pores from coarse to fine. It helps in smooth moisture transport and consequently drying. This diminishes the danger of developing drying shrinkage and plastic shrinkage cracks. Since the plaster after application of each coat is dried, it decreases the possibility of delamination to occur due to slow and inhomogeneous drying leading to the internal strains, which may cause disruption of the structure. This is based on the concept of wall preparation as is described earlier in the Section 6.8.

6.10 Non-Erodable and Water-Proof Mud Plaster

Shrinkage cracks, erosion and mechanical damage are the main defects of earth buildings. These are mainly caused by water penetrating into the mud walls. In improving the durability, measures are to be taken to keep the building dry and safe. The climate and topography, the layout, the properties of the soil, the design, the external rendering, the workmanship and the economy of the people are the factors that should be carefully considered. The problem of shrinkage cracks due to water penetration, and erosion by water are absent in dry areas, where the annual rainfall is less than 25 cms. In these areas especially in semi-arid and desert areas, wind laden with sand cause another form of erosion on mud buildings. The main problem in this areas are mechanical damage and wind erosion. These can be prevented by providing non-erodable enduring plasters.

Mud plaster is normally used in the rural areas which are not very durable and often need repairs or even replacement. It cost a lot of money and inconvenience to the inhabitants. There are different ways to provide protective rendering, which can increase the life of the structure. Apart from the protective renderings, resins and oils have been used with much success [UN1, 1964]. Some of the protective coatings are described here:

1. **Soil-Cement Plaster:** Portland cement rendering is commonly used on mud walls (mud-lime walls) to provide water-proof (dense, less permeable) non-erodable surface. The rendering is generally unsatisfactory due to imperfect bond between the mud walls and the cement mortar. Figure 6.16 shows a concrete plaster peeling from an earth building. Added to this is the tendency for rich cement mix to develop shrinkage cracks.



Figure 6.16 : Peeling of a rich cement plaster from an earth wall [Hammond, 1973].

Moisture normally penetrates, these cracks, softens the mud wall surface and destroys the bond. On drying, differential shrinkage develops between cement mortar and the surface of the mud wall. When this wetting and drying cycle goes on for sometime, the plaster peels off in slabs as is shown in the Figure 6.16. It is not advisable to use a rich dense mortar for rendering. Several mixes have been recommended, the richest of these is: 1 part of cement to four parts of sand [SB13, 1951]. Usually about a tenth part of hydrated lime is added to the mix to facilitate application and provide a degree of elasticity, to rendering. Such mixes as 1:2:9, 1:2:10 and 1:3:12, cement lime:sand have been successfully used.

Excellent results are obtained when the plaster is applied in two coats, each of about 1/4th in (6.35mm) thick. The wall is moistened before plastering and the first coat is cured for between 12 to 24 hours before the second coat is applied. The second coat is then cured under moist condition for 24 to 48 hours. Care is to be taken to prevent rapid hardening of the plaster. Cracks are reduced when the surfaces are made rough [External Rendering, 1948, Colonial Building Notes, 1953, Ideas, 1955 and HMSO, 1965].

2. **Soil Cement Mortars:** Mortars of soil cement are also used to provide waterproof non-erodable surfaces. Sandy soils are generally recommended. Mixes of one part of cement to about ten parts of soil are found suitable. Some lime is added to the mix to facilitate application. When this is done the amount of lime should not be more than 50% of the amount of cement. 'Before plastering reference points are noted on the surface of the wall at intervals 1.5m; thus, the thickness of coating and, consequently, "tightness" can be determined. "Guide strips" or master strips" mm wide are applied between the points of reference and left dry for 2 days. Mortar is then applied between two adjoining vertical strips and smoothed off, the surplus being removed by a scraper. This procedure is continued until the whole surface of the wall has been rendered [UN2, 1964]. In Congo (Brazaville) and Senegal (Dakar) plasters of different mixtures of lateritic soils, sand, cement and lime have been observed to show cracks after 10 years.

3. **Plaster of Lime:** Plaster of lime mortar is used in many countries where there is available good quality lime. "In Argentina for example, it is usual to follow this procedure: (a) a first coat of thick plaster, consisting of one fourth part of cement, one part of

paste of lime, three parts of brick dust (or an equal quantity of fine sand), is applied to the wall. (B) this coarse plaster is given a fine finish by covering it with a mixture consisting of two parts of lime paste to five parts of fine sand [UN2, 1964].

4. **Asphaltic and Bituminous Plasters:** Bituminous plasters are another effective water proofing agent. These are made from sand or soil and asphaltic or bituminous emulsions. Asphaltic emulsions are dispersions of very small drops of asphalt in an aqueous medium. The droplets usually range in diameter from one to five microns [AHB, 1967]. Asphaltic emulsions are of two types, the anionic and cationic. In the anionic emulsions the asphalt droplets are negatively charged, with alkaline water phase, whereas in the cationic emulsions the asphaltic droplets are positively charged with acidic water phase. It is not advisable therefore to mix the two together. It is dangerous however, to use anionic emulsions with electro-positively charged soils and cationic emulsions with negatively charged soils. The anionic and cationic emulsions have further been classified into three groups, namely:

- (a) R.S - rapid setting
- (b) M.S - medium setting
- (c) S.S - slow setting

The MS and SS emulsions have been found suitable for stabilizing plastering soils and for making blocks. Plasters stabilized with asphaltic or bituminous emulsions have been very successful [AHB, 1967]. The amount of bitumen to a soil depends largely on the soil type. Four to eight percent, even more has been used. In 1949, in India, a plaster containing 5% of bituminous emulsion was subjected to a rigorous test. The "rendering remained in perfect condition during the 144 hours spray test, followed by 50 cycles of wetting and drying [NBO, 1958].

5. **Plasters with Straw:** Straw has been used in manufacturing mud building materials since Biblical times (Exodus 3:7). In Ethiopia straw is considerably used in mixing "Chika": Amharic is the name for soil paste as plaster. 'If the "Chika" is being prepared for a first or rough coating of the wall, dry grass but preferably "*Chid*" is thinly spread over the mixture until it is uniformly distributed. If the chika is for the second or finish coating of the wall instead of grass, "*Chid*" the straw of "tef" millet (*Eragrostis*) is normally a must' [Makonnen, 1963]. The straw acts as a binder and

reinforcement to the soil paste. Nut shells and sea-shells have also been embedded in mud walls to resist water penetration or to provide base for plasters [UN. 1964].

6. **CBRI Plasters:** Non-erodible and water proof by the technique developed at the Central Building Research Institute, Roorkee, U.P., India [1973]. It comprises of 3 methods:

METHOD I

Preparation of Mud Plaster : The soil used should neither be too clayey nor too sandy. It is preferable to use wheat *bhusa* (chopped and crushed wheat stem), 4lbs of which should be used for every cubic foot of soil. The soil and *bhusa* (chopped straw) should be well mixed and the mixture kept wet and kneaded every day for about a week. This increases the workability and ensures the proper rotting of the *bhusa*.

Suitability of the plaster was tested by applying it over the wall in small patches. If it does not crack on drying, the plaster is suitable. If it cracks, then more sand is to be mixed.

Preparation of Cut Back : 100lbs of bitumen 80/100 penetration should be taken, warmed and the molten bitumen poured in 20lbs of kerosene oil slowly, while keeping the whole mass well stirred, and kept stirred for 5 minutes after the whole of bitumen has been added. 1 lb of wax is then taken, melted and mixed by stirring. It is preferable to keep the whole mass stirred for a longer period after all the ingredients have been added to ensure thorough mixing and proper product.

Preparation of Water Proof Plaster : For every 1 cu. ft. of the soil used in preparing mud plaster, 4lbs of cut back are added and mixed by turning over the mud plaster with *kodal* and kneaded. The plaster is applied in the usual way after proper mixing.

Leaping with Gobri : When the plaster has dried, a *gobri* (cow-dung) leaping is applied.

To prepare a material for leaping, 1 part gobri, 1 part soil mix is taken and mix with 4lbs of cut back for each cubic foot of the soil.

Method II

Mud plaster is prepared, as described in Method I, and applied over the walls in the usual way. When it has dried it is painted with a slurry prepared as follows:-

- 5 parts of slaked lime and 3 1/2 parts of fine sand, by volume are mixed together. Soap solution is prepared by dissolving 1 sunlight soap cake (soap used for washing clothes) in 4 gallons of water. To the mixture of lime and sand, soap solution is added so that a slurry like consistency is obtained. It is allowed to stand for about 4 hours, 4 parts of cement are then added and mixed. If required, more of soap solution is added to make the slurry workable with a painters brush. It is applied over the mud plaster surface.
- Before applying the slurry it is desirable to wet the surface with water. Wherever possible the slurry should be applied during evening hours so as to allow sufficient time for setting. In all three coats are to be applied. The interval between successive coats should at least be of 24 hours.

Method-III

Mud plaster is prepared as described under-Method I and applied in the usual way. When it has dried, it is painted with 2% silicon solution in water.

It is essential to note that the surface is free from major cracks before silicone solution is applied.

- 7. Non-erodable Mud Plaster with Ipomoea Carnea:** It is seen that the mud plasters are not durable, they crack, erode and show pitting. Some trials have been done to use Ipomoea Carnea in stabilization of mud plaster [Chand, et al. 1986]. The *Ipomoea carnea*, which grows wild in Madhya Pradesh, India and is locally known as "*Besharam*". It is a large diffuse and stout shrub, 2-3 meters high with spreading branches, containing milky juice [Haines, 1969]. The chemical composition of Ipomoea chips is shown below:

Lignin (extractive free basis)	16.59%
Cellulose (extractive free basis)	57.73%
Ash	6.45%
Pentosan	17.30%
Silica	0.6%

The cell structure of Ipomoea Carnea stem was studied by Scanning Electron Microscope. The microphotograph (Figure 6.17) is taken on the stems fracture at a speed of 0.001m/min. The cell do not seem to deform extensively before fracture which apparently follow the cell boundaries. At a few places near the multiple cell wall junctions the walls show void formation.

The density, elastic modulus and ultimate tensile strength of Ipomoeo Carnea and some other building materials are shown in the Table 6.2. It is seen that the strength and the modulus is very attractive to be used in the building materials. The strips were taken from the periphery of the stem, the density is 32gm/cm^3 . The density of the whole stem is even lower 0.28gm/cm^3 .

Table 6.2 : Strengths and Modulus of Some Building Materials [Chand et al. 1986].

<i>Materials</i>	<i>Density g/m³</i>	<i>Tensile strength MN/m²</i>	<i>Tensile modulus GN/m²</i>	<i>Flexural strength MN/m²</i>
Steel	7.8	410-480	210	
Timber	0.61	55-90	7-14	
Concrete	2.2	1.4	25	
Bricks	1.9	0.28-2.8		
PVC	1.38	34-62	2.4-4.1	
Ipomoea strips	0.32	16-25	1.84	
Ipomoea whole stem	0.28			50-100
Bamboo	66-73	100-200	14.0	66-121

Mud Plaster

Composition of mud plaster made with different compositions and with different types of natural fibers and the bond strength is given in the Table 6.3. Table 6.4 shows the comparative values of Ipomoeo carnea and bamboo reinforced plaster. The bond strength of bamboo with stabilized soil and cement mortar is also reported for comparison [Albert et al. 1985, and Humad, 1985]. It can be seen that the bond strength between Ipomoeo Carnea and mud plaster is of the same magnitude as between bamboo and mud plaster.

Mud plaster made from cement admixed with soil and wheat straw was put over the array of Ipomoeo stems. The load carrying capacity of 0.5 X 0.5 mud plaster with 2.5% cement is 300kg/m^2 giving a factor of safety of 3 against wind loading of 100kg/m^2 for single storey building. These results indicate that Ipomoeo carnea reinforced mud plaster is a suitable material for low cost walling elements since it gives factor of safety of 3 which is comparable to bamboo reinforced cement plaster wall panels which have a factor of safety of 5 [Kalia et al. 1985]. A view of the panel of Ipomoeo Carnea with cement stabilized mud plaster is shown in the Figure 6.18.

Table 6.3 : Ultimate Bond Strengths of Ipomoeo Carnea Stems (ICS) in Different Matrix [Chand et al. 1986]

ICS with mud plaster mixed with wheat straw	ICS with mud plaster with 2.5% cement + wheat straw	ICS with mud plaster with 5% cement + wheat straw	Bamboo with 4.0% cement + 10% lime + Black cotton soil	Bamboo with 1:4 cement : sand mortar
0.35kg/cm ²	0.70kg/cm ²	1.0kg/cm ²	1.5kg/cm ²	2-3kg/cm ²

1N/mm²=9.807kg/cm²

Table 6.4 : Ultimate Transverse Load of Mud Plaster Reinforced with Ipomoeo Carnea [Chand et al. 1986].

Mud plaster reinforced with Ipomoeo carnea stems	Ultimate Transverse load for panel of 0.5 x 0.5m
1. 2.5% cement + soil + wheat straw plaster and 14% vol. of IC mm diameter:panel size 50 mm x 0.5 m x 0.5 m	300kg/m ²
2. Cement :sand 1:4, split bamboo reinforced wall panel 38 mm thick 1 m x 1 m	500kg/m ²

Concluding Remarks

Various types of plasters have been developed and used in different periods, which were named after the place where they were developed and used. Composition of some of the plasters from different period differed from each other not only in the inorganic ingredients content like mud, lime, pozzolanic materials but also in the type and amount of organic materials, natural polymers.

The method of application of plaster is a mixture of art and science and needs knowledge and experience. Good, durable plastering is tedious and time consuming. It is depicted from the wall preparation for painting, which is accomplished in 30 steps. However, once it is made as is ascribed it lasts for 100^s of year.

Preparation of plaster, which is done by mixing aided by beating, and the technique of its application is very important from the durability aspect. Apart from the technique for use of plasters, significant role is played in selecting the composition of plaster with gradual grade variation from coarse to fine, which is done in different stages. It provides a systematic distribution of pores, which allows good moisture transport and drying facility. This minimizes the damages caused by fast and inhomogeneous drying and increases the durability. It is suggested that the backbone of long lasting durability of the plaster was the mixing technique and not the composition of the plaster. Modern plasters miss beating part whilst mixing and are not comparable in quality to the ancient plasters.

It is suggested to use thick plasters as thin plasters result in crack formation and are not durable. Polishing is another factor, which improves the brilliance of the color and enhances its longevity.

Ancient builders have selected the materials, prepared them, and applied them taking into consideration all the factors relevant for producing a quality plaster. This is why they last for so long time. This needs time which was no problem. Demand was on the quality, time was immaterial.

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7. MORTARS

Mortar is defined as any material used in a plastic state which can be trowelled, and becomes hard in place, and which is utilized for bedding and jointing. The word "mortar" is thus used without regard to the composition of the material, but simply defining its use as a bonding material. and to distinguish it from "stuccos" and "plaster"-

It generally consists of cementitious material at times pozzolanic material with or with out filler or aggregates. It may also contain mineral and chemical additives.

7.1 Properties of Mortars

7.1.1 Setting of Mortars (Pure or Fat Lime Mortars)

Mortars made with the addition of fat lime do not harden easily. It is found that even after hundreds of years there still is uncarbonated lime. Opinions about the fat lime mortars as given by different authors are briefed here:

Vitruvius

"Their use ought to be prohibited for ever at least in the works of importance."

Sir Charles Pasely

*"When wet it is a pulp or paste,
and when dry it is a little better than dust."*

Allen

"Pure lime, in itself, has neither power of setting nor ultimate strength, and it is only when combined with clay and burnt that it is of value as a building material...It is only fit for plastering and other sanitary purposes."

Ravington

"Speaks of the superficial carbonation; less than 1/2-in thick, the interior being a soft pulp or friable powder."

"Pure lime mortar built in thick walls never hardens or sets, but crumbles into a friable powder."

Cyclopedia of Civil Engineering

It is stated in the Cyclopedia of Civil Engineering: "The hardening of common lime mortar is due to the formation of a carbonate of lime by the absorption of carbon dioxide from the atmosphere. This will penetrate for a considerable depth in course of time. However there are instances in which masonry has been torn down after having been erected many years. The lime mortars in the interior has been found still soft and unset, since it was cut off from the contact with the carbon dioxide of the atmosphere. Similarly, the common lime mortars will not harden under water. Therefore, it is not advisable to use this for under water construction."

Dibdin [1911] reported that free lime was found in most of the samples of mortars taken from St. Pauls Cathedral, as much as 20 percent being found in one specimen taken from the core of a main pier. Other authors have also reported the presence of free lime in many old buildings made with fat lime mortars.

7.1.2 Fat and Hydraulic Lime

It is clear from the above examples that the process of carbonation can not be relied for strength development of mortars made of fat lime. Therefore, fat lime mixed with pozzolanic material or hydraulic lime is used. These harden and develop strength due to the pozzolanic reaction, developing hydraulic bonds and are independent of the carbonization process. These are described in the Chapter 1.2, Building Lime and Chapter 1.3, Pozzolanic Materials.

7.1.3 Workability of Mortars

The workability has an important influence on the adhesion between the mortar joints, the rendering and masonry stone. It affects the hardening process. Among others Piepenberg [1970] is of the opinion that mortar workability is of greater importance than the strength. With good workability the adhesion between the binder and aggregate is of high quality, as is that of mortar to the underlayer. The grain size and its distribution within the aggregate and the use of good quality binder influence workability, which should be easy to mix with good plasticity and good water retention property [Backman, 1953].

7.1.4 Effect of Moisture on Mortars

Water is essential for making mortars but it is deleterious also. Water initiates the hardening reaction by hydration and carbonation. On the other hand concrete deteriorates when the atmospheric pollutant gasses get dissolved in the moisture available in the pores and penetrates inside. This will create differentials in the salt concentration as the salt will crystallize or dissolve as a result of fluctuating atmospheric moisture condition. This will lead to the formation of osmotic and hydraulic pressure and will consequently damage the mortar. Several factors are responsible for the high moisture content in the old masonry. Some of them are mentioned below:

- Ground water rises freely into the structure, if not restrained by means of effective drainage or moisture barriers.
- A large number of masonry walls are directly exposed to rain water.
- Massive walls carry an irregular distribution of cold spots where the moisture condenses.
- Water-soluble salts are hygroscopic and thus readily absorb moisture from the atmosphere. This moisture imbalance in the structure.
- A large amount of water is used during the different stages of restoration work. This penetrates into the structure and influences the moisture balance.

Renderings may bring about a change in the behaviour of old masonry wall under the effect of moisture. A large number of walls of the old buildings were in good condition for hundreds of years, despite rising damp until these were rendered [Sandin, 1980]. Rendering may decrease or totally obstruct evaporation of ground moisture from the wall surface causing lower part of the surface susceptible to frost damage (Figure 7.1).

The rainwater easily penetrates the renderings. Its depth of penetration is controlled by the thickness and pore size distribution of the rendering and the condition of the under layer, specially its suction capacity. A rendering surface on a brick wall with weak absorption will readily become saturated with water. On the other hand a brick wall with a higher suction force than the rendering will continue to absorb water from the rendering once the rain has stopped. Under these conditions a greater amount of water will be present in the structure after a rain period.

As in the case of plasters, the mortar underlayer has a greater influence on drying rate of rendering. The fine structure of the underlayers is therefore very important. In the ancient period the surfaces were compressed after

laying different coats and were causing problems with the very fine pore structure.

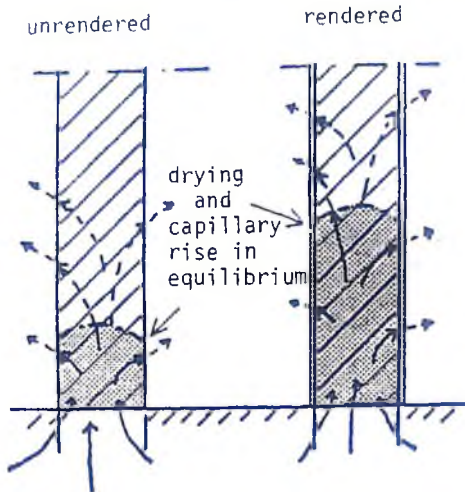


Figure 7.1 : Height of ground water capillary rise in rendered and not-rendered walls [Sandin, 1980].

7.1.5 Mortar Deformation

Mortars are applied in several coats, which have different properties. Moisture and temperature in each coat varies, as these are not directly exposed to the atmosphere. This influences upon movement of each coat. Durability of rendering is not due to one coat but due to the joint effect of all the coats. In other words, properties of each coat and their compatibility to the adjacent coats dictate the durability of the rendering. Free deformation between the rendering and the underlayer is restrained, leading to compression, tensile and shearing stresses due to varying intensities in their tendency to move. Stresses are caused by various factors. Some of them are mentioned here:-

- Movement in the building, e.g., settling.
- Shrinkage of mortar due to drying and hardening.
- Difference in temperature and moisture movement between the underlayer and rendering.

The relation between the stress and deformation properties of a material and the bond strength will influence the point at which yielding occurs, whether it be the rendering, the underlayer or the adhesion. In the three-coated renderings used, the mortar strength usually weakens from the inside outwards. Using strong rendering mortars on highly non-homogeneous masonry structures, which are dissimilar in strength, can cause breaking of the underlayer.

Lime mortars shrink during the drying and carbonation process, causing micro-cracks in the mortar. This is more pronounced in the high strength mortars. Low strength mortars safeguard against the micro-crack formation. Drying shrinkage can be controlled by optimizing the water to binder ratio, while mixing the mortar. This can be achieved by using appropriate chemical admixture.

The surface of the rendering will naturally be subjected to the greater fluctuations in temperature than the underlayer. Temperature variation will influence upon the moisture. This can weaken the bond between the underlayer. Consequently, the rendering or masonry mortar may shear away from the underlayer.

Mortar constitutes of binder, aggregate and additives, which influence upon the temperature variation. Since the greater proportion of mortar consists of aggregate, the temperature coefficient of the mortar will for the most part be influenced by the aggregate. Thermal properties of aggregates are different; temperature coefficient of limestone is smaller than that of quartz, it is still lower in the aggregates made of crushed bricks. With the use of limestone or crushed bricks as aggregates or additive, the temperature movement between the rendering and bricklayer will fluctuate safely. This is the reason why not so many cracks are seen in the ancient masonry structures made out of lime, pozzolan and crushed bricks or crushed burnt clay as aggregates. These constituents produce a well-balanced monolithic structure, which are compatible to each other.

Deformation is related to the modulus of elasticity. If the modulus of elasticity of mortar is low, major fluctuations in temperature and moisture will not lead to failures or defects. Failure rate increase reciprocally with the modulus of elasticity. For this reason cement mortars rich in binder are not recommended for renderings or for joints pertaining to natural stone masonry. Greater deformation will soon cause cement mortars to detach from the stone. Lime mortars are more preferred since they follow the deformation movements of the underlayer more readily than the cement based mortars.

7.1.6 Chemical Resistance of Mortars

In last decades pollution has increased by many folds. This has caused serious damages to the natural stones, lime mortars and renderings [Chandra, 1990]. Strength development in the lime mortars will be disturbed if sulphur dioxide gases are absorbed during the initial phase of hardening of mortar, which will interact with yet non-carbonated lime; calcium hydroxide, and will cause damage. The use of hydraulic lime or a lime-pozzolna combination overcame this problem, where the strength development does not depend upon the carbonation and there is not so much free calcium hydroxide to interact with the pollutant gases from the atmosphere. This is elaborated in Chapter 1.3; Pozzolanic Materials.

7.2 Type of Mortars

7.2.1 Mud Mortars

The oldest mortar used in building was made of mud. It is still used in many countries through out the world. In ancient Egypt mud mortar was used with sun-dried bricks. The Babylonians and Assyrians used several kinds of mortar; clay or mud, usually with chopped straw or reeds, but sometimes these were pure clay mortars without any fibrous material. At times natural organic materials have been added to increase the durability properties. These are discussed in the Chapter 1.1; Stabilization of Clay, and in the Chapter 4; Natural Polymers. Many of these buildings still are in acceptable condition speaks about their durability.

7.2.2 Gypsum Mortars

Gypsum mortars were used to join the blocks of stone and also as plaster on the walls at the beginning of the third millennium B.C. Buddhist monks used this together with mud and lime in the 3rd millennium B.C. for wall plaster and for flooring.

7.2.3 Lime Mortars

Lime mortars have long history behind them. It is basically a mixture of lime and sand. Sometimes a pozzolanic material is mixed in it. Lime mortars though are better resistant than mud mortars, yet they lack in adequate durability properties. Besides the durability aspect another drawback with the use of pure lime mortar which is non-hydraulic is that they harden very slowly. The hardening time is decreased either by using hydraulic lime or by adding pozzolanic material. In India, *Surkhi*, which is milled red brick is used as pozzolanic material. This increases the strength and modifies the

pore-structure, subsequently increasing the durability. The durability is further improved by the addition of natural organic materials. These are discussed in the Chapter 1, "Binders."

The old mortars were very thick, and lime rich. The aggregate content was very small, approximately 1.5-2.5 times of the binder content in comparison to the modern mortars, which contain 5-6 times aggregates to the mass of the binder. The sand used was pit sand or sieved river sand. Besides the pit sand, marble and crushed limestones have also been used in the medieval mortars. In addition to this, the aggregates made by crushing old hardened lime and mortars were also employed. Average particle size of the aggregates was between 0.2-0.5mm., with larger aggregates up to 1.5cm.

The grain size affects the properties of mortars in the fresh stage like workability and the pore structure of the hardened mortar, which governs the durability properties. However, the effect of aggregates is comparatively small in the old mortars, as the particle size is very small.

7.3 Mortar Classification

The properties of mortar are mainly controlled by the type of binder used, which is related to the type of raw materials used for producing it. Vicats has given the following classification of the binder;

- Non-hydraulic, or lime rich <10% foreign matter
- Hydraulic lime; 10-34% clay and 60-40% lime
- Cements, 40-60% clay and 60-40% lime
- Pozzolanic cements, 70 to 90% clay and 30 to 10% lime.

7.4 Mortar Preparation

The quality and the type of binder, aggregate, the grain size distribution of the aggregates, and the particle size distribution within the aggregates influence workability. Besides the ingredients, the workability is also influenced by the quality of mixing. Ancient mortars were prepared by very careful mixing which was accomplished by mixing aided by beating with wooden clubs. This provides better compaction and adhesion. This quality of mortar is not easy to achieve by mixing in the modern mixers. For example in free fall mixers the mortar is unlikely to undergo sufficient homogenization or plasticisation. In ancient time stress was given on the workability of mortar as it has an important influence on the adhesion between the mortar joint, the rendering and the masonry stone. It also affects the drying and hardening process. Good workability insures good adhesion

between the binder and aggregate and the adhesion between the mortar to the under layer, which are important factors for the durability properties.

Some of the mortars based upon lime and lime + cement based on the report of Sen Gupta [1953] are elucidated.

7.4.1 Lime Mortar

The mortars were prepared by mixing and grinding lime putty, sand and *Surkhi* in specific proportions usually 1:2 (1 lime: 2 sand, surkhi etc.) measured in boxes of suitable sizes on a water tight platform or troughs or grounded in masonry lined mortar mill driven by cattle. The track of the mill was sloped outwards and kept well consolidated and watered mixture. No dust or mud is allowed to fall into the mortar being grounded.

In case of small work, where the use of mortar mill or mechanical mixer is not feasible, the mortar may be hand mixed. The ingredients of the mortar which can be used in small quantity, shall be then mixed dry on water tight masonry platform or in trough or in a pit by hand mixing with a shovel adding required quantity of water giving the mortar necessary working consistency. The mortar shall be used on the day it is made.

Unit of Measurement

The unit of measurement for cement is a bag of cement weighing 50 kg and this shall be taken as 0.035 cubic meter (cum); sand shall be measured in cubic meter and the lime shall be measured in quintal. 4.51 quintal of unslaked lime being equal to 0.58 cum or 0.7125 cum of lime putty.

For dry mortar, the ingredients for 1 cum of work are; 1.426 cum.

i.e. Cement = 0.178 cum or 0.25 ton

Lime = 0.178 cum or 1.13 quintal or 0.15 cum unslaked lime

Sand = 1.07 cum

Total = 1.426 cum

7.4.2 Lime Cement Mortars or Compo-Mortars

Compo-mortars are a mixture of lime, cement and sand. It is usual to mix the lime mortar as already explained and then gauge this mixture with the necessary proportion of cement just before the use. The addition of the cement increases the hydraulicity of the mortar. Thereby the rate of hydration, and hardening is accelerated; subsequently the strength is increased. The general ratio of mixing is 1:1:6 (1 cement: 1 lime: 6 sand) or 1:1:10 or 12.

7.4.3 Cement Mortars

Cement mortars are stronger than the lime mortars and are therefore used in the construction work, where higher strength is required. The usual composition is 1 part of cement to 3 parts of sand. The unit of measurement is a bag of cement weighing 50kg and this is taken as 0.35 cum. Sand in the specified proportion is measured in boxes of suitable size (35 x 25 x 40cm). The mixing is done either in a mechanical mixer or manually, as explained earlier in the case of lime mortar. Cement mortars even though possess higher strength, are not suitable for use in many cases, mainly due to its lower elastic properties. It is explained separately.

7.4.4 Special Mortars

In construction, and for repair of inlay work, marble work, special mortars were used. The composition of one such mortar is as follows:-

White lime or marble	500gm.
Marble dust	400gm.
Burnt zinc powder	300gm.
Gum	100gm.
<i>Gur</i>	100gm.
<i>Urad ki Daal</i>	100gm.
<i>Patacha</i>	100gm.
<i>Mastagi</i>	50gm.
<i>Tukhm Balanga</i>	50gm.

Gum is first soaked in water and other ingredients are ground in the gum-water to form a thick paste. When ready, it is kept in earthen pots, well soaked in water and taken out as required. The mortar will remain fresh for a week or ten days.

7.4.5 Mortar of Marble Shade

To get the marble shade for 18mm thick plaster done on the sandstone floor or walls etc, the following ingredients are used:-

For under coat of 12 mm thick cement plaster 1:4 (1 cement: 4 sand) or lime plaster 1:2 is used. 6-mm thick middle coat of Makrana lime paste, fine marble particle and stone dust in the ratio of 2:1:1 are applied. Finishing is done with *Urad ki daal* and *Misri*. 1.5kg each for an area of 10m² is rubbed with *Muslin* cloth.

7.4.6 Mortars for Pointing the Rubble Stones Masonry

For pointing the joints of old buildings built in rubble stone masonry during the Mughal Period, a mortar composed of 1:1:3.5 or 6 (1 lime: 1 cement: 3 coarse sand and 5 or 6 brick Zira aggregates) was used to harmonize with the old mortar in strength, color, and texture. It is to remember that generally the old mortar consist of *Kankar* lime mixed with crushed burnt brick aggregates.

7.4.7 Lime Mortar for Lime Base Concrete

For lime concrete over the terrace, generally 50% lime mortar 1:2 (1 lime putty: 2 surkhi) is mixed with 20mm to 25mm normal size brick aggregate, thoroughly mixed in the mechanical mixer or by hand and laid over in a single layer on the terrace to a slope, rammed and finished with *Gur and Belgiri fruit* treatment. The thickness of concrete laid depends upon the depth of old concrete. But for 10cm thick concrete for an area of 10 sq.m or 1 cum concrete, 0.25 cum of 20mm size brick aggregate, 0.75 cu. meter of 25mm size brick aggregate and lime mortar (1:2) 0.50 cu. meter is used. The surface shall be liberally sprinkled with a mixture of *Gur* and solution of *Belgiri fruit in water*, in the proportion of 1.75kg of *Gur* to 1kg of *Belgiri fruit*, boiled in 60 liters of water. As soon as the beating of the mortar is completed, the mortar that has come on the top shall be softened with a solution of *Gur and Belgiri fruit*, smoothened with a float or trowel to a fine polish. No plaster shall be used for finishing the roof.

7.4.8 Cement Mortars for Portland Cement Base Concrete

Concrete consists of binder, aggregate and water. The aggregates are of two types; fine and coarse. Fine aggregates are from sand and the coarse aggregates are from stones or the crushed burnt bricks. It is generally used in the foundation, in the R.C.C work, in the floor and in the roof construction. The proportion of which varies from 1:2:4 to 1:4:8 (cement: coarse sand: stone aggregate).

7.4.9 Mortars for Diverse Uses

Mortars for different uses both based on lime as well as cement are summarized in the Tables 7.1-7.3.

Table 7.1 : Mortar for Plaster

<i>S.No.</i>	<i>Types of masonry</i>	<i>Thickness of plaster</i>	<i>Proposed ratio for cement mortar</i>	<i>Proposed ratio for lime-cement mortar</i>	<i>Proposed ratio for lime mortar</i>
1	Brick masonry	12mm to 20mm	1:4(cement:fine or coarse sand)	1:1:1:6 (cement: lime putty:sand)	1:2 (lime:coarse sand or surkhi)
2	For ceiling	12mm	1:3 (cement: fine or coarse sand)	do	do
3	Artificial sand stone plaster	18mm under layer, 12mm finished with a 6mm thick coat	1:4 (cement: fine or coarse sand)	1:1:3 (cement: marble dust: stone dust mixed with red oxide)	
4	Stone masonry, rubble or coarse	20mm to 50mm	1:6 (cement: fine sand or coarse sand)	1:1:6 (cement: lime putty: fine or coarse sand)	1:2 (lime putty:fine sand or coarse sand)

Table 7.2 : Mortars for Pointing

S.No.	Types of work	Types of pointing	Proposed ratio for cement mortar	Proposed ratio for lime cement mortar	Proposed ratio for lime mortar
1	Brick work in masonry	Flush ruled weather struck raised	1:3 (cement: fine sand)	1:1:6 (cement: lime: fine sand)	1:2 (lime: fine sand or surkhi)
2	Brick work	do	1:2 to 1:4 (cement : fine sand)	-	-
3	Stone work, new work	Stone	1:3 (cement:sand)	do	do
4	Rubble stone, old work		1:1:3:6 (cement: lime: sand: brick zira)	do	do
5	Marble work		1:2 (white cement: Marble dust)		

Table 7.3 : Mortars for Different Kind of Masonry; Proportion of Lime Mortar and Cement Mortar used for Different Kinds of Masonry

S. Nr.	Types of masonry	Proposed for cement mortar	Proposed for lime-cement mortar for lime mortar	Proposed ratio
1	Brick plain	1:6 (cement:coarse sand)	1:1:6 (lime :cement:coarse sand)	1:2 (fine:coarse sand or surkhi)
2	Brick work in arches	do	do	do
3	Random rubble masonry with hard stone	do	do	do
4	Coarse rubble masonry with hard stone	do	do	do
5	Ashlar stone masonry	do	do	do
6	Ashlar stone masonry in domes or arches	1:3 (1 cement:coarse sand)	1:1:4 (lime putty:cement:coarse sand)	1:1 (lime putty:sand or surkhi)
7	Sandstone in veneering or <i>chajja</i> work	1:4 (cement:coarse sand)	1:1:4 (lime putty:cement:coarse sand)	1:2 (lime: sand or surkhi)
8	Red sandstone <i>Jali</i>	1:3 (cement:coarse sand)	do	do
9	Marble stone in pillars, steps, <i>jambbs</i> , etc.	1:4 (white cement:sand)	-	-
10	Marble work for lining (veneering work)	1:3 (white cement:sand)	-	-

7.5 Mortar Additives

Lime mortars require time to develop strength and consequently to acquire the durability properties. Time is expensive these days. This has led to the search for the additives, which can help in early strength development. The materials, mostly the natural organic, which were thought to be the possible additives, were tested. The probability of their use was ascertained by trial and error method. Some of the additives used are mentioned here.

7.5.1 Traditional Additives

Additives in the ancient times were limited to casein, egg whites, linseed oil, fresh ox blood, beeswax, keratin (from animal hooves and horns), tallow (animal fat), beer, malt and urine.

Bitumen was sometimes used as a substitute for or an additive to the lime when working on the riverside or docks.

Waxes, fats and oils introduced some water-repellent properties to mortars; sugar containing materials work as water reducing agents but they retarded the hardening process, beer and urine worked as air entraining agents.

7.5.2 Some Examples of Traditional Mortars

Lime-oil Mortars (Putty)

Lime oil mortars are made with hydrated lime, silver sand and oil. Hydrated lime and silver sand are mixed dry in the proportion; 1:1 or 1:1/2 and gauged directly with enough oil to form a stiff paste. These mortars are used where fine white joints are needed.

Lime Tallow Mortars

Lime tallow mortars consist of; 1 part fresh quick lime, 1-3 parts well graded quartz sand and or flint aggregates and tallows (animal fat). These mortars are made first by warming up the aggregates, adding shredded or soft tallow while the aggregates are still warm, to this fresh quick lime is added. These mortars are used for treatment of the finished joint faces. In high humidity, and warm climatic conditions, application of a biocide is recommended to inhibit the mould formation.

7.6 Ancient Mortars

Mortars in the ancient period were prepared using mud or lime or both as a binder. Some times gypsum was also used. Their strengths were improved by the addition of pozzolanic materials like brick powder, brick chips or marble dust. These mortars were very resistant to weathering, which was accomplished with the addition of additives like, milk, eggs, honey, jaggery, vinegar, blood etc. Casein was also used in the form of skin milk or skin curd.

The historical mortars were lime rich. The mixed proportion of binder to aggregate in most of the cases was between 1:2 and 1:5.

The structure of modern lime is different compared to that of the ancient times. It is because of the difference in lime production and its slaking technique. As a consequence, the hardened mortars had less capillary pores and the shrinkage is decreased. Thus a mortar prepared using "historic" slaked lime can stand a higher portion of binding materials without getting shrinkage cracks.

7.6.1 Methods of Mortar Analysis

It is not so easy to analyze the ancient mortars. A group of tests are to be performed. Such as oxide composition can be found by chemical analysis, mineralogical composition can be ascertained by the X-ray diffraction analysis, porosity and pore-structure is possible to determine with the help of mercury intrusion porosimeter and the microstructure and weathering behavior can be investigated with the help of microscopes. This enables to ascertain the basic composition like if the mortar was lime based or gypsum based but for example the information about the addition of natural organic polymer is not so easy. By Infra-red spectroscopy however it is possible to confirm the presence of amino-acid groups, indicating the presence of protein, but which was the original material used which contained this protein is not so simple. May be some speculations can be done if one looks into the geographical situation of the place and find out the vegetation and the commodities around it in the period when the particular building was constructed. Some of the methods of analysis are described here.

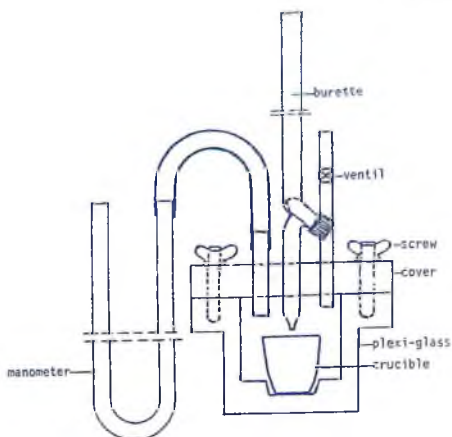


Figure 7.2 : Calorimeter for determination of calcium carbonates.

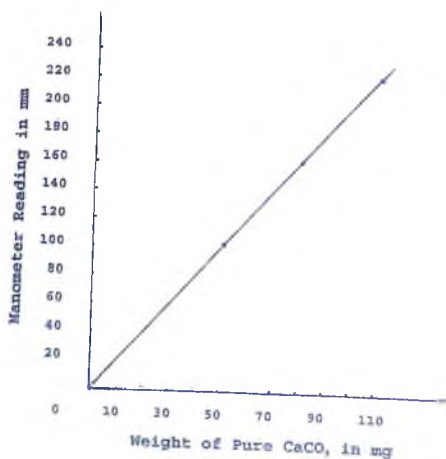


Figure 7.3 : Calibration curve for determination of calcium carbonate.

Simple Method of Analysis

By this test the three basic components of the mortars are determined; (i) the binder, (ii) the impurities like fine textured clays, and (iii) the sand or aggregates.

- (i) The binder :The mortar is crushed and treated with hydrochloric acid solution. It dissolves the binder, which is mostly calcium carbonate.
- (ii) The fines:The impurities like fine textured clays which are dissolved in water and is separated.
- (ii) The sand or fine aggregates: The residue after the above treatment is the sand or the fine aggregate. With the help of simple microscopes, the color, size and the shape of the aggregates can be determined.

The particle size distribution of the aggregates is determined by sieving this through the standard sieve set

Calcimeter Method

Jedrzejwska [1960] has developed a method for dermining calcium carbonate. A schematic diagram in the Figure 7.2 shows the apparatus. The principle is that when hydrochloric acid comes in contact with CaCO_3 , CO_2 gas is evolved, which is measured by the manometer attached to the dessicator containing the sample. This apparatus is calibrated by testing pure calcium carbonate first. A curve is drawn showing relation between CaCO_3 and CO_2 evolved. With the help of this calibration curve, amount of calcium carbonate is directly read with respect to the CO_2 gas evolved from the test samples. A calibration curve is shown in the Figure 7.3. This method was modified at the Chalmers University of Technology, Sweden [Chandra, 1979]. Jedrzejwska did not take the change in temperature into consideration. In the modified method the dessicator is put under a water bath maintained at a constant temperature to keep the condition adiabatic.

By this method also three components, carbonates, solubles, and sand is determined.

- (i) Carbonate: It is calculated by the following formula:

$$\% \text{ CaCO}_3 = \frac{p + vkc}{760} \times \frac{273.6}{273.16 + t} \times \frac{v(\text{cc})}{1000} \times \frac{100.29}{22.414} \times \frac{100}{\text{mat}}$$

Where

- p = Room pressure
 v = Volume change
 t = Room temperature in $^{\circ}\text{C}$
 k_c = Constant of instrument (0.221)
 Matg = Mass of sample in gm

- (ii) Soluble: The substances soluble in the acid without producing carbon di-oxide. These are calculated by adding the percentage of carbonates and sand and subtracting them from 100.
- (iii) Sand : The amount of sand is expressed as a simple W/W percentage of the whole sample.

By this method total amount of CO_2 gas evolved is measured. Thus it determines the total amount of carbonates present. It may be from the carbonation of lime or from the limestone or dolomite used as aggregates. It does not differentiate between them. Thus it will not be possible to ascertain the amount of lime used as binder with this method. It is only possible when no minerals in the carbonate form have been used as aggregates.

Phenolphthalein Test

Phenolphthalein is a chemical, which indicates the change in the pH value. It produces red colour in alkaline environment and gives no colour in acid or neutral environmental condition. Calcium hydroxide is highly alkaline $\text{pH} > 12$ and calcium carbonate is almost neutral. Phenolphthalein can thus be used to ascertain the presence of calcium carbonate.

A solution of phenolphthalein is made and sprayed over the fresh broken surface of mortar. The part, which becomes red, shows the presence of calcium hydroxide and the part, which does not show any colour, shows the presence of calcium carbonate. The thickness of the colourless part is measured by the calipers and is reported as the carbonation depth. This is a measure of carbonation, which has taken place after a particular time. So this value can not be used as a measure of total lime (calcium hydroxide) present in the mortar.

However, in case minerals containing carbonates have been used as aggregates, besides the clear demarcation of colourless boundary from the surface there will also be colourless spots on the overall surface. It will indicate that the carbonate minerals have been used as aggregates. But it will not be possible to quantify them.

X-ray Diffraction Analysis

X-ray diffraction analysis shows the mineralogical composition of the constituents in the mortar. Different minerals have their characteristic reflections at particular angle, which is recorded by the x-ray diffractometer. The minerals are identified from these reflections. For example; a strong peak of Portlandite will show calcium hydroxide, the peaks of aragonite, vaterite or calcite will show calcium carbonate; which are three crystal forms of calcium carbonate.

This has also its limitations. By this method minerals only having well crystalline phases are detected. Minerals with crypto-crystalline or amorphous phases do not give any reflection, and thus cannot be detected. Thus this will not give total calcium hydroxide present.

Microscopical Method

Microscopic analysis is more complicated and needs experience in the identification, and explanation of the crystal structure observed. Microstructure is studied with the help of Transmission Electron Microscope (TEM) and the Scanning Electron Microscope (SEM). Thin section is used for studying with TEM and for studying with SEM, samples are only coated with gold or carbon under vacuum. Some of the salient features of TEM are mentioned here.

- (i) If brownish coloured particles are observed together with a diffused cloud like pattern, it is suspected to appear from the iron containing compounds. It shows that hydraulic lime was used.
- (ii) Glassy particles show the presence of hydraulites.
- (iii) The mortars prepared with dry slaked lime or mixed with quick lime show round inclusions of calcium carbonate with diameters up to some millimeters. Crystalline marble occurs chiefly in the form of isometric, sharp edged grains.

One of the thin section microphotograph of typical old mortar as analyzed by TEM is shown in the Figure 7.4 [Thorborg and Råman, 1985]. These show the distribution of aggregates, binder, and pore structure. It shows that the mortar is rich in binder and is relatively porous, with irregular pore shapes. The mortar binder is non-homogeneous and the lime is carbonated. Lime was frequently under-slaked and limestone with clay impurities was used as raw material. Lime lumps present in the mortars can be distinguished in the binder as an uniform mass. The aggregate has a similar mineralogical composition to that of aggregates used in modern

mortars, but the grain size of old aggregate is very different from that of today. In the old mortars the aggregate particles are round, and ash and crushed bricks are found in addition to the burnt clay. All of these act as hydraulic binder to some degree.



Figure 7.4 : Microscopic photo of a typical old mortar [Thorborg and Råmar 1985].

7.6.2 Analysis of Some Ancient Mortars

The mortars used by the Indus valley people consisted mainly of mud. In the later period gypsum cement of a light colour was employed for painting the walls of certain buildings at Mohenjo-daro. Some of the mortars from ancient period like from; Mohenjodaro, Harrappa, Taj Mahal etc were analyzed. The samples were analyzed by Sane Ullah [1965]. Some of the results are given here;

Mortars from Mohenjodaro

Mortars from Hr. Site Wall

Sample No. 1

Gypsum $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	74.12 %
Calcium carbonate CaCO_3	2.50 %
Sand	20.41%

Alkaline salts	1.10
Moisture	1.79
Total	100.00

Sample No.2

Gypsum	63.25%
Calcium carbonate	1.64%
Sand	31.52
Alkali salts	2.58
Moisture	1.01
Total	100.00

Mortar from S. Site Tank

Sample No.3

Gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	43.75%
Calcium carbonate, CaCO_3	13.78%
Sand	38.04%
Alkaline salts	2.47%
Moisture	1.96%
Total	100.00

Sample No.4

Another sample of mortar consisted of 56% gypsum, 25.0% calcium carbonate, the remainder being sand and foreign matter.

Sample No. 5

A sample of mortar found in an earthenware vat at Hr. site

Gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	Nil
Calcium carbonate	69.58%
Sand	21.71%
Alkaline salts	5.41%
Moisture	3.27%
Total	100.00

Sample No. 6

Mortar from drain	
Calcium carbonate, CaCO_3	39.96
Magnesium carbonate	8.82
Clay and sand	17.43
Gypsum	traces
Moisture	3.74
Total	100.00

Sample No. 7

Sample of mortar employed for painting on a wall at Mohenjo-daro was found to contain 72.3% gypsum and was free from lime.

Mortar from Harrappa**Sample No.1.**

Mortar from Floor, Trench VI

Calcium carbonate, CaCO_3	35.02%
Magnesium carbonate, MgCO_3	10.62%
Clay, Sand etc.	51.39%
Gypsum	Traces
Moisture	2.97
Total	100.00

Sample No.2**A Lump of Mortar**

Calcium carbonate, CaCO_3	56.51%
Magnesium carbonate MgCO_3	4.81%
Clay, Sand etc.	34.35%
Moisture	4.37%
Total	100.00

Sample No.3**Mortar from Floor T.I**

Calcium carbonate, CaCO_3	26.5%
Magnesium carbonate MgCO_3	3.16%
Clay, Sand etc.	61.60%
Moisture	3.41%
Total	100.00

Samples No. 5 and 6

Sanne Ullah has analyzed 2 more samples. The analyses is given in the Table 7.4.

Table 7.4 : Analysis of Samples 5 and 6

<i>Nr. Sample</i>	<i>Gypsum</i>	<i>CaCO₃</i>	<i>MgCO₃</i>	<i>Clay + sand</i>	<i>Alkali</i>	<i>Water</i>
1 Painting of circular platform	56.6	0.94	-	42.16		-
2 From concrete floor	Traces	37.63	2.13	50.22		-

Table 7.5 : Proportion of sand to slaked lime from Kausumbi

	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>	<i>8</i>	<i>9</i>	<i>10</i>
Sand	55.16	59.34	51.1	52.92	39.63	32.9	50.8	23.77	50.96	29.95
Slaked lime	27.55	19.01	34.57	27.23	31.23	21.6	25.5	23.11	25.10	36.0
Sand:Lime	2:1	3:1	3:2	2:1	1:1	3:2	2:1	1:1	2:1	3:4

Although lime mortar free from gypsum was not discovered in the walls at Mohen-jodaro, the mortar found in the earthenware vat at this site, consist of lime and sand. It was entirely free from gypsum. It had been established that gypsum mortars have been employed extensively in the later periods at Mohenjodaro. But it is interesting to note the discovery of a lime mortar free from gypsum at Mohenjodaro as well as a number of them at Harappa.

The high proportion of clay and sand in these samples is noteworthy. Therefore, it appears highly probable that the lime used was red lime made by burning the *kankar* or the calcareous nodules which are widely found in the Upper India. This even now constitutes an important source of lime mortar. Agarwal [1953] has also mentioned the use of *Kankar lime*. The burning of lime in the period of Indus Valley Civilization is well established. But its use was restricted to drains or floor where better higher durability properties were required than the common mud mortars posses.

Mortars from Kausambi

Further studies on the ancient mortars from Kausambi [Satya Prakash and Rawat, 1965] have reveled interesting facts. These mortars date back from 600 B.C to 100 A.D as per evidences from the Archaeological Survey of India. It is interesting to note that a number of mortars constituted of only mud.

It appears from the Table 7.5 that the sand in the mortar was added in slightly higher proportions than in the plasters. The average ratio of sand to lime, in the case of plaster as found was 1:1 whereas in the case of mortar the average ratio was 2:1. For mortars probably two parts of sand were mixed with one part of slaked lime.

Thus it can be concluded that at Mohenjodaro apart from mud mortars, gypsum mortars were generally in use whereas at Harappa a number of lime-mortars have been used.

In the Mughal period the simple cementing material was plain earth or clay mixed with water but it was the weakest mortar. An improved kind of plaster had straw added to a mixture of clay and water.

Special mortars used for waterproof construction were called *Saruj*. It was quite expensive and was employed sparingly. This mortar was made of lime, sand and wood ash.

Some examples of the mortars from the Mughal period are given here. The example cited here include the mortars from the world famous Taj Mahal.

Mortars from Taj Mahal

In general hydraulic lime mortar was used in the construction of Taj Mahal. In addition to this, some special lime mortar was also used, which constitutes of marble lime, marble dust, *Nimi Mastagi*, *Batasha* and *Belgiri* water in proper proportions. Three samples were taken from the first floor corridor where the masonry was damaged. Physico-chemical analysis was carried out both on the aggregate and the mortars [Aslam, 1987].

The Type and size of aggregates is shown in the Table 7.6, mineralogical composition is shown in Table 7.7 and chemical analyses in the Table 7.8.

Visual Characteristics of the mortars:

	TM1	TM2	TM3
Colour; exposed	-	-	-
unexposed	light buff	dark buff	reddish buff
Aggregates; Coarse	Present	Present	Present
Fine	Present	Present	Present
Lumps of lime	Present	Present	Present
Fibers	Absent	Traces	Traces

Mineralogical Analysis

It was done by XRD and SEM

	TM1	TM2	TM3
Calcite	Abundant	Substantial	Abundant
Quartz	Substantial	Abundant	Abundant
Mica (Muscovite)	Substantial	Present	Present
Feldspar	Traces	Absent	Absent

Table 7.6 Type and Size of Coarse Aggregates

Sample	Type	Max diam mm	Colour
TM1	Calcareous gravel	10	Grey
	Calcareous gravel	8	Black
	Siliceous gravel	12	Dark brown
TM2	Non- calcareous	8	Black
	Calcareous	12	Dark brown
	Siliceous	12	Dark buff
	Marble	10	White
TM3	Calcareous	13	Reddish buff
	Calcareous	10	Dark buff
	Calcareous	8	Black

Table 7.7 : Mineralogical Composition of Mortars from Taj Mahal

	TM1	TM2	TM3
CaCO ₃	57.53	32.75	18.01
MgCO ₃	4.01	4.18	3.40
Ca(OH) ₂	0.30	0.22	0.14
Quartz	16.68	33.08	3.6
Non-hydraulic comp.	15.40	10.04	18.06
Hydraulic comp.	5.52	0.18	10.68

Table 7.8 : Chemical Analysis of Mortars from Taj Mahal

	TM1	TM2	TM3
Loss on ignition	28.15	17.73	16.13
Acid ins. residue	31.00	51.63	56.15
Ins. HCl 1:1	31.26	52.12	56.12
SiO ₂ total	26.73	27.19	22.13
CuO	35.20	23.10	24.25
MgO	1.02	2.00	3.25
Fe ₂ O ₃	0.91	0.87	1.01
Al ₂ O ₃	2.10	1.78	1.54
Na ₂ O	1.02	0.39	0.11
K ₂ O	0.90	1.25	1.75
CO ₂	37.31	22.60	20.40

Mortar from Fatehpur Sikri

A lime mortar of special composition was used in marble mausoleum of Sheikh Salim Chisti.

Composition

1 part lime: 2 part marble dust

1/16 Rumi mastagi: 1/16 parts Urad Ki Dal and 1/16 part Batasha.

Mortar from Charminar

Qutb Shah, the fifth ruler of the Qutub Shahi Dynasty of Golconda, constructed it during the years 1591-93.

The material used in the construction of Charminar is locally available granite, lime and sand. Analysis of the mortar reveals that the SiO_2/CaO ratio in Charminar varies from 1.61-2.25. It indicates that the engineers at that time were probably aware of the necessity of having higher SiO_2 content but were not sure of the optimum value at which the maximum strength of lime cement could be obtained.

It is seen from the analyses of mortars that these were made with hydraulic lime, calcined gypsum, and marble dust. The lime was not burnt 100%, as indicated by the lumps of lime, a characteristic feature of ancient lime mortars. The pozzolanic material was pulverized bricks, Surkhi, and ash. The aggregates used were crushed bricks, burnt clay lumps and limestone.

These were prepared and applied taking into consideration all the factors, which help in producing good faultless mortars.

Report on the Analysis of Marcole Soil from Laddakh (Leh)

There is a very special type of clay found in the Leh, Laddakh, in the region of Jammu and Kashmir State, India. This has extremely good bonding properties and is used even in building the airstrip at Laddakh. It is mixed with a local wine, which acts as a chemical admixture and the local soil as the thickening and filling material. It is also used for making the mud bricks, mud plasters, filling the cracks and bulges etc. The composition of the clay is given below:-

Loss on ignition	Due to loss of water of hydration, crystallization 2.2.1% 4.05%
SiO_2	Due to change of composition and decomposition 1.84%

(ii) R_2O_1	32.23%	Fe_2O_1	9.0%
		Al_2O_3	23.23%
		TiO_2	< 5ppm
		Fe_2O_5	< 5ppm
		MnO_2	traces
		CaO	2.13%
		MgO	3.76%
		Na_2O	2.32%
		K_2O	1.24%

It has very high alumina and iron content. Consequently it works like a strong binder.

Concluding Remarks

Ancient mortars were rich in binder and were porous. Lime used was frequently under-slaked and was made from limestone with clay impurities. Fat lime was not preferred owing to its inability to provide strength without carbonation which takes very long time. Generally hydraulic lime or lime-pozzolana were used as binder. Sumptuous amount of aggregates was used in making the mortars. The properties of mortars therefore very much depend upon the quality of aggregates and the bond of the binder to the aggregate. This can be acquired by using the mortars of good workability having good water retention property.

The aggregates should be very carefully selected specially because they vary very much in their thermal properties. Uneven expansion and contraction of the aggregates produces cracks. In the ancient mortars, mostly crushed bricks, burnt clay or limestone were used as aggregates because these are compatible to the lime mortars and produce a monolithic structure.

Mortars like plaster are laid in several coats, which have different moisture and temperature, the factors responsible for the movement. The behaviour of a rendering is a combined effect of the coats. Coats are to be made with carefully selected aggregates, binders and additives, and are to be laid in a way so that they should be compatible to the adjoining coat. This will decrease the risk of deformation.

Mortars in the ancient period were made with carefully selected binders, aggregates and additives. These were applied in a way so as to produce a high quality mortar. The type and quality of mortar depended upon the place where it was to be used and to the environmental conditions to which it was to be exposed.

Mortars of low modulus of elasticity are to be used as in this case, major fluctuation in moisture and temperature does not take place and there will be less risk of deformation. This is the reason why Portland cement mortars are not recommended and lime mortars are preferred.

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8. WORLDWIDE USE OF NATURAL POLYMERS

Natural Polymers, NP, were not only used in India to enhance the strength and durability properties of low strength lime and clay base materials. These were also used in the other parts of the world. One of the oldest natural polymers used was bitumen, a noncrystalline, semisolid, or viscous mixture of complex hydrocarbons derived from petroleum deposits.

8.1 Bitumen, One of the Oldest NP

Bitumen occurs naturally in rock asphalt and in lake asphalt. The main source of lake asphalt is from Lake Trinidad in the British West Indies. It is a fluid mixture of bitumen, very fine silicious silt, clay and some insoluble organic matter. Another source is the natural seepage through the veins in the earth, which have absorbed wind blown sand and other matter to form a kind of asphalt. Such a deposit occurs in many part of the Middle East from Egypt to Pakistan. It is this asphalt that is assumed to have been used in the early civilization for bonding brickwork, for damp-proofing, for lining of drains, water basins, bath etc. Location of such type of seepages include Burgan in the Arabian desert not far from Kuwait, Quijirah, Ramadi and Abu Gir, west of Baghdad, and Bundar Abbas in Iran on the Persian Gulf. Bitumen is also present in Dead Sea. Although bitumen is found in these areas, the use of asphalt has not been much identified in these places. However, Garstang [1932] reported that the walls at Jericho in South West Asia, were cemented by bituminous earth in about 2500 to 2100 B.C.

The greatest use of bitumen was made in Babylonia, in what is now Iraq (see Figure 8.1) in the fourth millenium B.C. The most important supplies were at Hit in the neighbourhood of Babylon. Simiranis, the natives of Babylon, used asphalt in the mortars for binding clay bricks in walls surrounding Babylon, for protecting exterior masonry surfaces for trowelling over the surfaces of the interior floors, and for making water-resistant baths and drains. The temple of Ur-Nina, King of Lagash (approx. 2800 B.C) in

8.1.1 Asphalt as a Water Proofing Material

Apart from the use of asphalt as an admixture to enhance the adhesiveness of the mortar it was also used for water-proofing. The use of asphalt as a waterproofing material spread up to the Indus valley, 25 miles south of Larkana, in Sind, Pakistan, and its performance was appreciated. The Indus valley civilization two cities appear to have been Mohenjo-daro and Harappa (3250-2750 B.C). The location of Mohenjo-daro and Harappa is shown in the Figure 8.3. Most of Mohenjo-daro was built of kiln-fired bricks. At Mohenjo-daro, there is a massive mud-filled brick embankment, and on its summit are the remains of several impressive structures, the most prominent of which is called Great Bath (Figures 8.4 and 8.5). The pool is surrounded by a paved courtyard, made of bricks and made water tight by bitumen [Marshall 1926].

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Figure 8.3 : Map showing the location of Mohenjo-daro.



Figure 8.4 : Great bath of Mohenjodaro.



Figure 8.5 : Interior of the bath.

It is further reported that in the temple of Borsippa, the clay was omitted from the joints and the asphalt was used as sole binder and was in direct contact with the bricks. Then there was a gap and the asphalt was not used very much until the time of the Great King Hammurabi (Amraphel of the Bible, c.2000 B.C). Later in the sixth and seventh century B.C asphalt mortars were used for joining the glazed bricks. Their bitumen content was higher than was used for bricklaying.

These mortars were also used in making embankments, for example, for the river Tigris in the reign of King Adad-Nirari I of Assyria, in 1300 B.C. A retaining wall was first built with limestone blocks. This masonry was protected by outer wall of burned bricks joined by bituminous mortar consisting of bitumen and loam or sand and gravel (Figure 8.6) [Davey 1961].

Bituminous mixtures were also used in construction of roads in ancient babylon, more particularly for the processional or royal roads connecting temples with the royal palaces. A good example is the road called Aibur Shabu [Davey, 1961] , a section of which is in Figure 8.7.

The use of asphalt again came in practice after a lapse of 2000 years, when in 1712 Eyrinus, a Greek, used powdered asphalt rock with hot pitch to make surface floors. This led to the discovery, and asphalt powder with bitumen was used instead of pitch, with better surface obtained. It was successfully used in France, Switzerland, and Germany for floors and pavements.

A notable example is the surfacing of the Place de la Concord in Paris in 1835. Later, in 1869, the first roadway in England, Threadneedle Street in London, was resurfaced with rock asphalt. From that time onward, bituminous asphalt became an indispensable material, used for roofing, damp proofing and flooring in building construction.

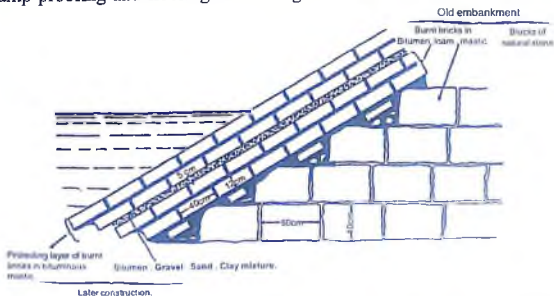


Figure 8.6 : Construction of Tigris Embankment at Assur, [Davey, 1961].

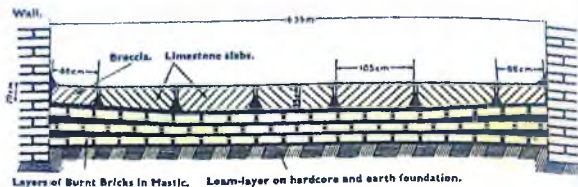


Figure 8.7 : Section of the road Aibur Shabu at Babylon [Davey, 1961].

8.2 Use of Other Natural Compounds

Apart from the bituminous material plenty of other types of natural materials have been used in the building constructions. These are agro-products, cereals, vegetables, Juices from trees, fruits, herbs etc. Details of these natural polymers is given in the Chapter 4. Here use of some natural polymers in different parts of the world is elucidated.

8.2.1 China

Glutinous rice and viscous liquid obtained from soaking the elm shavings in water were used in the construction of important buildings [Huang, 1990]. For example in the construction of the Great China Wall (Ten Thousand Li wall), prominent pagodas like Lonhua Pagoda in Shanghai, palaces and temples, and monolithic tombs.

Polished glutinous rice was cooked so as to form a paste. This was mixed and stuck with the dry lime powder to form a dense, sticky lime mortar to lay the heavy brick blocks in constructing the huge masonry wall (The great China Wall, Figure 8.8) In the second case, the natural polymer used was the viscous liquid used for construction in monolithic tombs. The dry lime powder was spread *in situ* layer by layer, and a suitable amount of viscous liquid was spread successively and alternately. Each layer of lime with viscous liquid was immediately compacted to form layers of polymer lime mortar in the form of a tomb wall. This process was repeated up to the completion of the whole tomb. In this way a massive, monolithic construction could be produced. Huang estimates the life of structures with glutinous rice to be more than 1000 years and those with the viscous elm bark soaked liquid more than 500 years.

In about 1840 the hydraulic binding material Portland cement appeared in China, and its use gradually spread in construction engineering. A great number of common structures were built using concrete. Nevertheless, lime is still used as a chief binding material for common purposes in the traditional

way. In special cases, other natural polymers such as Chinese lacquer, tung oil, and animal blood were used to produce high strength, durable construction.



Figure 8.8 : The Great China Wall.



Figure 8.9 : Hu Qion Pagoda at Suzhou.

In 1990, Chandra visited Hu Qion Pagoda and Han Shan Shi Temple at Suzhou, an old town about 150km. from Shanghai. This Pagoda was built in the 12th Century, and the main entrance at the foot of the tiger hill was built in the 15th century. This Pagoda looks very similar to the leaning tower of Pisa in Venice, Italy (Figure 8.9). It even tilts in the same manner. Han Shan Shi temple was built in 502 to 510 A.D. and reconstructed in 1910. Some repair work was going on during the authors visit. It was interesting to note from the analyses of the repair mortar done at the Chalmers University of Technology, Göteborg, Sweden, that the lime mortar used for the repairs contained rice hull and stems of rice plants. Besides this, some sort of fiberlike material (may some special type of paper) was also mixed. The mason working on the site explained that the natural polymers of these types are frequently used for the repairs of historical buildings.

8.2.2 India

In India various types of natural polymers were used. These are described in the Chapters 4, 5, 6 and 7. Some of the excerpts are described here.

Vicat [1837], coats on the Indian stucco as is given by Thevenot in the appendix to Chapter IV.

In India, they plaster the walls with a rough coat of quick lime slaked with milk, and beaten up with sugar, and that they afterwards polish the mortar with an agate. The fact is, that they mix the lime with a curdled milk, with gingeli oil, and water of jaggery, a coarse very brown sugar, which is derived from the cocoa trees.

This edition of Vicats book was translated in 1828 by colonel J.T. Smith R.E., an engineer from Madras. At the same time Smith added some of own experiences with mortars. In the reference to the above Indian Stucco he gave a "celebrated Madras" recipe with similar constituents.

In about every bushel... mix the whites of ten or a dozen egg, half pound of ghee (which is butter separated from its caseous parts by melting over a slow fire) and a quarter tyre (which is saur curd fresh prepared, which some add powdered balapong (or soap-stone) from a quarter to a pound, which is said to improve the polish. But, each master bricklayer has generally a recipe of his own, which he thinks is the best. The essential ingredients, in addition lime and sand, seems to be the albumin (of eggs), and the oily matter of the clarified butter, for which oil is sometimes substituted.

Smith recommends rubbing the wall, once dried with soapstone or agate.

In India, different materials have been used at different places, partly due to the climatic conditions and partly owing to the local availability.

Some examples are given for the plasters used on the wall for paintings. These plasters were used during 4th to 6th century [Muni Singh]

Ajanta Caves: The plaster contained of clay, cow dung, stone powder, rice husk and lime.

Sirgiria Caves: The plaster contained tempered clay (kaolin), rice husk, coconut fibers, and lime.

Bagh caves: The plaster contained of red clay, maurang, lime, and jute.

According to Mansoullas [1976] the plasters to be applied on the walls consisted of powders of cronch, *kaths*, pulses (green and black gram), molasses, boiled bananas, sugar, oils, eggs, milk etc. The method of applying the plaster on the wall is described in the book *Chitrasutra of Vishnu Dharmottara* [1976]. It is done in many sages, which are briefly described here:

Brick powder of three grades (fine, medium, coarse) are mixed in equal proportion. To this mixture, is added fragrance of gum resin, molasses, and saf flowers (*kusum flowers*) soaked in oil, in equal proportions. To these two parts already composed is added powder of lime (three fourth burned) with *Bel* fruit pulp and lamp black. The remaining fourth part added is sand.

Then the mixture is soaked in water, stored in a pot so as to get lubriceres, and kept so for a month. When it becomes a soft paste, it has to be taken out, and a coat is applied on the wall after testing to assure that the wall is dry. When the wall is dry after coat and still not quite smooth, it is smoothed by using clay bereft of *Sargaresa* and oil. Further the surface is frequently wetted with milk and polished. The wall dries soon, and it does not perish for hundreds of years. The painting from Ajanta cave is shown in the Figure 8.10. It is in very good condition. The colours have not faded out.

In the villages, it is a normal practice to use mud for making houses. In many cases mud is mixed with leaves from the trees and is left for some time. When the leaves start rotting and become soft, the mud is kneaded to mix the leaves properly. The mixture is used for making blocks or as stucco; it makes a crack-free stucco. When a wall thus made is dry, it is plastered using cow dung. This treatment substantially reduces water absorption. In regions, where there are cashew nut plantation, cashew nut shell liquid resin is used. It decreases significantly water absorption and gives adhesiveness to the plaster [Jain, 1986]. Many types of natural polymers have been used in India. These are mixed in different proportions with

white lime, red lime, broken red bricks as aggregates and sand. The fact that some of the structures are still in good shape today shows the durability of the materials used (Figures 8.11 and 8.12).

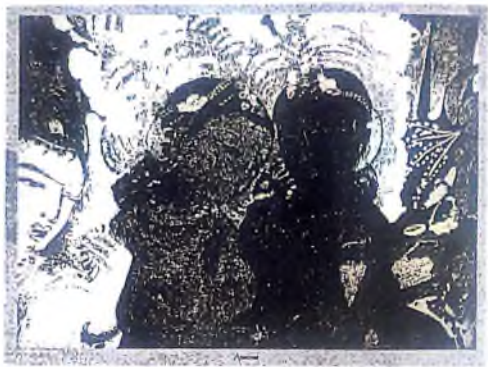


Figure 8.10 : Painting from Ajanta cave.

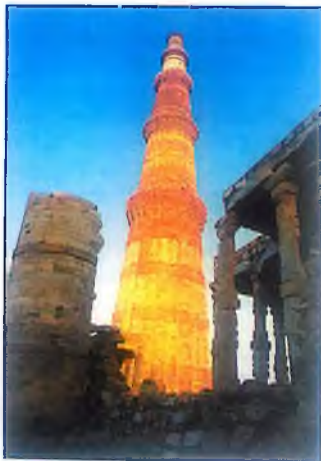


Figure 8.11 : Qutub Minar, New Delhi [Photo Chandra].



Figure 8.12 : Taj Mahal, Agra, [Photo, Chandra].

8.2.3 Africa and South America

Some examples of stable adobe structures are the walls at Chan Chan and San Pedro de Raachi in Peru. These are 700-800 years old and are a reference showing that in Africa and South America latex from rubber plants (*Euphorbia lacter*) was used as waterproofing paint at adobe [Clifton, 1977]. In other areas paints were made by boiling the stems and leaves of banana plants. In Peru, a glue fluid obtained from cactus plants was mixed with lime and was used for painting abode walls. In northern Ghana, walls are plastered with mud stucco mixed with manure and an extract obtained by boiling pods from the *locustan tree* [Schrenkenbach and Abanka]. Walls made at the Catholic University of Peru [Ernesto et al, 1988] show that it is possible to obtain a crack-resistant stucco composed of soil, a coarse sand, straw, and a viscous solution made from cactus plants. The impermeability of this stucco can be further enhanced by stone polishing the surface before it is exposed to rainfall.

8.2.4 Europe

Early Records

The earliest record of the use of natural polymers in mortars and stuccos dates back to the last century B.C [Richardson, 1870]. Lucas [1926] have analyzed some of the existing buildings and has revealed that the natural

organics have been used. Neuberger [1930] in his book, *The Technical Arts and Science of the Ancients*, states that the ancients have used arabic gum or tragacanth, animal glue from Rhodes, the blood of the hippopotamus and the milky juice of figs mixed with yellow of the egg, all as binding substances. In Egypt, egg albumin, keratin and casein were common natural polymeric binders used [Sayre, 1930]. Juice of figs, rye dough, hog's lard, curdled milk, blood and the egg whites were used to regulate the setting time and to toughen the structure [Bankhart, 1808].

Pliny's *Natural History* (23-79 A.D) is an exceptional work elaborating the use of natural polymeric materials [Bostock and Riley, 1855]. Though he seldom explains as to why one substance is better than the other one or what is the difference between them, he has explained the difference between the type of blood and the type of milk. It is very important to understand as the blood differs from human being to the animals and from one animal to the other. The main problem is when the right type of blood for example is not used one gets bad results, which are later generalized and published as ***"the blood is not good to be used in the building materials."*** These are the outcome of the lack of knowledge and understanding.

"The blood of the bull coagulates and hardens the most speedily of all..

Blood is the richest quality in the ass and the poorest in man.

The blood of the wild boar stags, roe-buck and oxen of all kinds does not coagulate."

The properties of milk also vary depending upon the breed of the cow, season and the time of milking.

Cow's milk immediately following a birth is "Colestra", and will coagulate and assume the hardness of pumice.

All milk thickens by the action of fire and becomes serous when exposed to cold.

Early lime plaster or stucco had very low strength, it was made using fibrous plant materials or coarse animal hairs mixed in for gain in strength [Hodge, 1964, Chandra and Van-gemert, 1997]. For example, Justinian church of the Baptist, Constantinople, elm bark and hot barley water (tannin and size) were mixed in the stucco [Bankhart, 1808].

The selection of polymeric material was done by trial and error. The materials tested were locally available. Nevertheless, the mortar generally contained at least one organic substance. At the temple of Minerva, Elba

states that the mortar was blended with *milk and saffron* [Bostock and Riley 1845]. Later he describes in detail a special cement called Maltha, where three organic compounds were used:

Maltha is a cement prepared from fresh lime; lumps of which are quenched in wine, then pounded with hog's lard and figs, both of them, nollifying substances. It is the most tenacious of all cements, surpasses stone in hardness and is extremely adhesive [Bailey, 1932].

After application Pliny also recommends rubbing the surface with oil.

Records from Middle Ages

Despite the fall of the Roman Empire in 476 A.D. and the highly advanced technology that was suddenly lost, the use of organic compounds continued. At the end of 9th century bullocks blood was mixed in the stucco and mortar for Rochester Cathedral in England (Figure 8.13). At Silvertown in 1279, wax, pitch, sulphur and eggs were used [Salzman, 1952]. Also during this century, queen Eleanor's cross at Charing Cross, London was erected using the white of eggs and the strongest wort of malt mixed with lime and Calais sand. Later still during the 16th century, urine was used at Rouen [Bankart, 1808]. A recipe given below is an example of using malt and eggs.

"Six strikes of malt to make mortar to blend with lime and temper the same, and 350 eggs to mix with it, viz. to seven quarters of lime."

In the 15th century there was immigration of Italian craftsman to England, who brought with them some of the knowledge, ideas, skills and the literature used in Rome and its surroundings. This might have helped to further increase the use of organic additives.

Increase in Literature

The peoples awareness about the use of organic compounds increased due to the increase in the availability of literature, particularly pattern books, treatises and tradesman journals.

Some of the are worth mentioning here. Sir Hugh Plat [1653] wrote The Jewel House of Art and Nature, where he describes a stucco that was greatly used in Italy.

“Temper ox blood and fine clay together and lay the same in any wall, and it will become a very strong binding material.”

He also gives egg white in another recipe as a substitute for arabic gum.

“Beat the white of eggs into a thin and clear oley or water; put the same into bladders, hang them in your kitchen chimney, where a fire is usually kept in the day time, and in a few days the same will become hard as Arabic gum.”

Richard [1703] has given two recipes for cement, which were made by using organic compounds:

1. **Cold Cement:** Take half a pound of old Cheshire cheese, pare off the rind, and throw it away: cut or grate the cheese very small and put it into a pot: put to it about a pint of cows-milk, let it stand all night. next morning get the whites of 12-14 eggs, then take a pound of best slaked or quick lime that you can get, and beat it to powder in a mortar, then shift through a fine hair sieve, into a tray or bowl of wood, or into an earth-dish, to which put the cheese and milk and stir them well together with a trowel, or such like thing, breaking the knots of cheese, if there be any, then add the whites of eggs and temper all well together, and so use it. This cement will be of a white color: but if one would like to have it of the color of brick, put either some very fine brick dust, or almeagram, not too much, only just to color it.
2. **Hot Cement:** Take one pound of Rozin, a quarter of a pound of Beeswax, half an ounce of fine brick dust, half an ounce of chalk dust, or powder of chalk; shift both the brick dust and chalk-dust through a fine hair sieve (brick and chalk can be beaten together in mortar before shifting), boil altogether in a Pipkin or other pot, about quarter of an hour, stirring it all the while with an iron or a piece of lath, or something similar, then take it off, and let it stand 4 or 5 minutes, then it is ready for use [Richard, 1726].

In 1703 Moxon published “Mechanik Exercises” [Moxon, 1703]. There he discusses the lime produced from different sources such as from shells

of fish or cockles, oyster etc. Later he expounds on the ancients techniques of adding organic matter, and almost quotes Pliny verbatim on the use of Hog's Lard, ox-blood, glue and egg whites.

Norman Davey [1961] in his book has listed various additives used in lime stucco in England by the mid-18th century.

*“rye dough, barley water, hog's lard,
bullocks blood, cow dung, wort
and eggs, wort and bear, milk,
gluten, butter milk, saponified
beeswax, fig and other fruit
and vegetable juices.*

In the 19th century despite the growing use of cement, the journals continued to mention-however briefly- organic compounds for use in mortars [Parker 1756, Aspdin 1924]. Vicat (1786-1861) in his book discusses these constituents twice. The first account is in Chapter XI on mortars exposed to the air and weather.

In those situations in which it is impossible to avoid the use of rich lime, it may be useful to be aware that their bad qualities may be to some degree corrected by the use of a comparatively small quantity of the coarsest sugar dissolved in water with which they are worked up. This substance (or jaggery) is extensively employed in the East... for the common mortars made of calcined shell... resist the action of the weather for centuries, and there is no doubt that this is in great part to be attributed to the use of sugar, the influence of which on the first solidification of the mortar is very marked. Even in UK, it may occasionally be found advantageous to employ the cheapest sugar, or molasses, when work of importance have to be stuccoed with rich lime, for its aid is chiefly confined to the hardening of the outer surface [Vicat 1837].

Burnell [1850] also briefly mentions organic compounds. He states that the french used “lime pounded bricks, gum andragan and the white of eggs to set delicate mosaic. However, briefly these treatises mention organic constituents. Nevertheless, it shows that people were aware of their use.

In the middle of 19th century came such periodicals as "The Builders" in 1843 and "The Land and Building News" in 1856 [Anon, 1856]. These magazines promoted various organic ingredients in mortars by printing peoples recipes and their experiences using them. In the March 1843 issue "The Builder", Colonel Maceroni [1843] gave his "New cement recipe". Considered a marine cement, it used the white of egg and oyster shell lime to make a "good quality of cement", but the best he states, was made using shellac as a vehicle.

More articles were published in "Cements and other Composition", June 1843 issue, which lists mortar recipes with organic compounds, Dr. Higgin's patented cement or stucco (1779) and Dr. William's patented mortar or stucco (1780). In particular, Higgins used lime and bone-ash, while Dr. Williams used like Higgin's and grated skimmed milk cheese [Maceroni, 1843].

The 23 August issue of "The Land and Building News" [1856] also printed an article on Mortars and cements" Although it discusses these items in more general terms than the other periodicals, it does list one Turkish cement recipe that used

"100 pounds of picked kilned lime...

10 quarts of linseed oil, and

one or two ounces of cotton..."

This is the only place where the author came across the use of cotton. Chandra has tested, linseed oil, maize oil, and mustard oil both cooked and raw in Portland cement mortars. It is shown that their addition significantly improves the resistance against water absorption and thence the durability properties are significantly improved [Chandra and Xu 1995].

The noteworthy work that deals with organic constituents on a large scale is Cooley's [1880]. It explains the chemical and physical properties of the organic compounds.

Table 8.1 : Some natural organic materials and the dates of their use [Sickles, 1981].

	150 Egyptian	46 B.C. Vivianus time	23 A.D. Pliny	800 A.D. Rochester Cathedral	Middle Ages		1653 Plat	1703 Neve, Moxon	Mid-1700s	1873 Vicat Smith	1850 Burnell & Periodical
Albumen	X										
Animal	X							X			X
Glue											
Barley			X						X		
Beer					X	X			X		
Beerswax					X	X		X	X		X
Blood	X	X	X	X		X	X	X	X		X
Butter										X	
Casein	X										
Cheese								X	X	X	X
Cotton											X
Curdled milk		X							X	X	
Dung									X		
Eggs	X				X	X		X	X		X
Eggwhites	X	X			X	X	X	X		X	X
Elm bark			X								
Fig juice	X	X	X						X		
Fruit juice					X	X			X		
Gluten					X	X			X		
Gum arabic	X					X	X				X
Hogs lard		X	X					X			X
Kerain	X										
Malt					X	X					
Milk		X	X					X	X	X	X
Molasses										X	
Oil			X							X	X
Rice								X			
Rye dough		X							X		
Saffron			X								X
Shellac											X
Size			X		X	X					
Sugar					X	X				X	
Tannin			X								
Urine					X	X					
Vegetable juice									X		
Wine			X								
Wort					X				X		

Some of the organic compounds used and discussed here with the dates of their use is given in the Table 8.1.
[Sickels, 1981].

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9. VASTUSHAstra

INDIAN

ARCHITECTURE

The fundamental aspects of *Vastushastra* are related to the philosophy and religion. A place of living, which will make the resident happy, is a prerequisite or rather the essence of the Sanskrit word *Vastu*. Creation of such a *vastu* requires a definite planning, considering as to what effect the occupant will have on his mind, body and prosperity, when he will live there. In Indian Architecture, all aspects such as Philosophical, Religious, Astronomical, Geographical, Geological and Cosmological are taken into consideration to its minutest details. Survey of land, site selection, soil examination is the fundamentals of architecture planning.

The science of erecting any structure or building on site means, in common language, *vastushastra*. *Vastushastra* belongs to, and is, applied Astrology, Astronomy and Astrophysics. It is enumerated as an *Upveda*, subordinate to the *Atherveda*. This science if followed properly, gives definite and positive results to the occupants. The construction may be of any type, whether a house or multistory building. If the rules laid down are followed, there shall always be happiness and prosperity, but otherwise it shall be detrimental and will bring misfortune to the occupant.

In fact, we, Indians are fortunate enough as our ancient sages and learned men in the past have provided for us the fundamental knowledge of design and construction of a house, which proves auspicious and beneficial. *Vastushastra* was conceptualized thousands of years ago through an in depth study and a thorough research. The competence and vision of these men is beyond comparison. This being a science for mankind as such, with time tested credentials has no limitations of space, age and religion.

9.1 Astrological Aspect

The site selection for building a house was considered a critical criterion. Besides this there was another aspect which was of great concern even today at many places in India. It is connected with the astrological aspect.

While purchasing a land, the astrologers were consulted to see if this particular land would suit to the person buying it. It was only after the consent of the astrologer the land was purchased. That was possible when the land was not scarce. Here the author wants to emphasize that in India people are superstitious and believe in the astrology. They believe that the human body is influenced by the position of the stars (*Nakchatrya*). When a person is born, it is a custom that a Brahmin will make the horoscope according to the exact time of the birth, where the position of the stars is mentioned. The position of the stars is changing with the time, and so is the life cycle. The life of the person can be predicted basing upon the position of the stars which is published every year in "*Patras*". The person having good knowledge of astrology can do it very precisely. The astrologers are looking into the land and the horoscope of the person and only then give their consent. Now a days neither there are so many knowledgeable astrologers or so much choice of buying the land and the possibility of building the house alone. This became only an ancient Myth. However this science is also fading successively.

9.2 Astrophysical Aspect

The design of the house to be constructed was made taking into consideration the "Vastushastra", which is mainly connected with the selection of site, survey of land, soil examination etc. The major principle of design of the house; placement of the windows, doors, kitchen, bedrooms is based on the electro-magnetic field existing in the land where the house is to be built. There is an astrophysical aspect of Vastushastra also. The basic concept of this science has its root in the solar system, with the sun assuming the prominent role. The sunrays reach the earth through radiation. The radiation seems to consist of seven colors of rainbow. The number seven seems to have some significance as there are seven colors of a rainbow, seven parts of the day and in the mythological tales, the sun is supposed to traverse the whole universe through the day in a chariot, which is drawn by seven horses. Here, the seven Horses indicate Seven deities. The seven colors are named as *Parjana*, *Kashyapa*, *Mahendra*, *Surya*, *Satya*, *Bhrush* and *Nabhas*. The Seven divisions of the day are; *Brahma Muhurta*, *Usha*, *Arun*, *Pratah-Sangav*, *Madhyam*, *Aparanha*, and *Sayankal*; which correspond to very early stage of dawn, dawn, morning, mid-morning, noon, afternoon, and the evening.

The sunrays have different effect at different hour of the day in different direction. The scholars indicated the effects these rays have in different directions and instructed as to what functions should be performed in a particular direction and what would be its consequences during the day. They also put light on the method of radiation and the manner in which these rays get spread over, during pre-noon to post afternoon period. In the morning, the quality of radiance is very high, while there is a devilish power in these rays during the afternoon. The sunrays are fierce between noon and afternoon and their ferocity decreases as evening approaches.

At the appearance of planet Venus in the sky, as "*Brahma Muhurta*" (pre-dawn stage commences, pious people begin to offer prayers and engage themselves in meditation. This period lasts for 2 hours i.e. from 3 a.m. to 5 a.m. equivalent to 5 *Ghatikal* (Indian time unit, each equivalent to 24 minutes). Then dawn lasts for only 36 minutes (i.e. 1 1/2 *Ghatikal*) followed by morning and past morning lasting for 24 minutes and 6 minutes respectively. After this, the sun makes the appearance, in the sky. during this period, evil doors, people with criminal instincts and those involved in different sorts of vices whither away. Whereas animals like cows and birds get awakened after a nights rest. Later on, the common man set about his daily chores, the travelers take to their routes and birds take a feet in the sky. This is a common routine through out the world.

9.3 Five Elements

The entire universe is constituted of the five elements viz. Earth, Water, Fire, Wind, and Sky (*Chiti, Jal, Pawak, Gagan, Samira*). An ideal house should maintain an equilibrium in the existence of these elements in the house. The design and construction of the house should be such that the circulation and being of these elements in the house should be in harmony with their characteristic roles in the environment. A disruption in this synchronism will result in turbulence in the life of the resident. The subtle forces in nature work in anonymity to take a person to the realm of success or down to the depths of misery, failure and desperation. However, if a little carefulness is observed in the construction of a house or the layout of the house according to the principles of Vastushastra, mankind will experience a renaissance in the environment and a transformation of themselves into better beings than they ever been.

In analogy, it is essential that these five elements in the Universe also form an integral part in the house, with each of them in its appropriate form and place. This leads to the evolution of peace and happiness in the house

with its residents in perfect health and ideal state of existence. Man is also a manifestation of five elements. If these five elements in the man will have a harmony with the five elements in the house, he will lead a comfortable life. Vastushastra strives to achieve this equilibrium and harness all the possible happiness under the given conditions.

9.4 Citations in Puranas

Systematic description of this science is given in the Indian mythological books (*Puranas*). To name a few;

“*Skand Purana*” deals with town planning, “*Garud Puran*” deals with residential and religious places of worship: “*Agni Puran*” deals with the residential properties, “*Narad Puran*” gives more details about temples, lakes and wells. While “*Vayu Puran*” explains about the construction of temples on hilltops. “*Matsya Purana*” specially deals with the design and construction of columns. It says that there are mainly five types of columns viz. A square column (*Brahma Kanth*): Pentagonal column (*Shiva Kanth*): Hexagonal column (*Scand Kanth*): Octagonal column (*Vishnu Kanth*) and a circular column (*Rudra Kanth*). Details regarding their construction importance and materials used therein are also given.

9.5 Criteria for Land Selection

Some simple tests are to be performed before making a decision for buying the land, which will give the information about the fruitfulness of the land for the buyer. Some of the tests performed and the other factors of relevance are narrated here;

A very simple test to be performed on the land gives us a first hand knowledge about its suitability for construction, and whether this deal is going to be beneficial.

“The test involved in digging of a knee-deep pit on the site and then refilling the same with the excavated material”.

- If the backfilled material spills over the pit, then the site will bring riches to the purchaser.
- If it levels out, the purchaser can expect an average life-style.

However, if the pit falls to level off then it is mandatory that the purchaser will encounter a lot of hardships and mishaps.

One important point is to be kept in mind i.e. from the day of purchase of a plot till the completion of construction, any growth of Cactus, Carvanda, Pongara, Tembhurni, Aghada should be totally destroyed and removed. Such growth have disastrous effects on the head of the family, such as loss of wealth, death of some close member of the family or even the death of the head of the family.

9.6 Time of Construction

The other factors which are of importance are; the geometry of the land, the time when to start construction. The time of starting a construction is of utmost importance. It is described in the part "foundation". The ideal time for starting a new construction is the period, when there is congregation of sevens, i.e. Shravan month, Saturday, Swati Nakhatra, Shukla Paksha (full moon fortnight), Saptami (seventh day), Shubhayog and Sinha lagan (i.e. Ascendent Leo). This will always give all benefits, riches and happiness. The placement of the main door, bathroom, kitchen, bedroom, study room etc. is also governed by the cosmic environment prevailing in the house. Their placement is very important for the healthy atmosphere and for well being of the occupants. The detail descriptions are given by Bruno Dagens [1994] and Arvind Vaze [1995]. In very short the method of positioning the main door and some of the internal arrangements are given here.

9.7 Method of Positioning the Main Door

There is a certain method to ascertain the exact position of the door. First measure the length of a house along the direction in which the door is to be placed. Divide the length into equal parts. Leave out 5 parts to the right and 3 parts to the left, and place the door along the remaining length. This procedure holds good for any direction.

If the length of the house is 18 feet, then 9 parts will be of 2 feet each. After leaving 5 parts from the right side and 3 parts on left side, the remaining part, which will be 2 feet where the main door should be, installed. This procedure is to be followed, if the floor area is divided into 81 parts. The right and left flanks are also determined in a specific manner.

9.8 Internal Arrangement

Allocation of different areas within the house for specific purpose is given here. Appropriate works if performed in appropriate directions, they play a vital role in the prosperity and the well being of the occupants. Such rules are described in a verse, which is in sanskrit. Its meaning is translated in English and is summarized.

Place of worship	North-east
Bath Room	East
Kitchen	South east
Bed Room	South
Storage for utensils	South west
Dinning Room	West
Storage	North-west
Valuables	North

REFERENCE

1. Bruno- Dagens [1994], Mayamtam, Indira Gandhi Center for Arts, Janpath. New Delhi, p 913.
2. Vaze Arvind [1995], Ache Vastu Arvind, Amaraj Prakashan, Waknis Building, Mughbhat Street corner, Girgaun, Bombay, India, p 150.

10. BUILDING CONSTRUCTION

10.1 Introduction

In India earthen architecture is common in the rural part and in the suburb of the urban part. It constitutes a major part of the countries culture. Earth is the cheapest building material and is available in abundance. It creates a very good monolithic structure, which can be molded and tailored according to the will. The rooms in the earthen houses are often dark and badly ventilated. But these are ideal considering the cost, and simplicity in making them. Moreover, they provide comfortable living in the tropical climate prevailing in the major part of India, Asia and other African countries i.e.; warm in the winter and cool in the summer. They suite very well to the adjustments in the prevailing climatic conditions. The houses can also be decorated by painting the inner walls. Examples of such decorations can be found in different states of India like Bihar, Karnataka, Punjab and Uttar Pradesh. India is divided in different states; these are shown by a map in the Figure 10.1.

Inspite of the fact that the 85% population live in the villages, there are no qualified planning to improve the living standard specifically to improve the quality of the mud houses; their durability properties. As such there are no co-operative societies in the rural areas who are making the house complexes like in the urban area. The individuals generally make the houses. The architecture of the house depends upon the size and location of the land and the material to be used, which subsequently depends upon the financial condition of the person. The poor peasant for example builds the house with earth and thatched roof, whereas the “Sarpanch” head of the village builds the house with kiln burnt bricks. The standard of the house thus goes up with the status, which is mainly affiliated with the economical situation of the person. The material for building the house and the technique of its application also varies accordingly. For example a rich person can afford to hire an architect for designing and skilled masons for advising about the material and building of the house. The houses can be categorized on the basis of the materials from which they are built.

- Mud houses
- Houses with sun baked bricks
- Houses with burnt bricks

Besides the normal houses of the people there are other type of buildings like the palaces, temples, mosques etc., which have different type of importance and thus require special attention for its outside look from the aesthetic view point, and also the interior construction from the comfort view point. Finally the concentration is given upon the life length of the structure: durability, which primarily depends upon the materials used and the way in which the construction is done.



Figure 10.1 : Map of India showing different states of India.

10.2 Mud Houses

There are three parts to be considered while constructing a house: -

Foundation

Walls

Roof

Foundation, walls and roofs are constructed from the material of similar quality which suites each other and not that one is made of high quality material and the other with low quality. The materials used are compatible, so they do not create differential stresses causing damage to the house.

10.2.1 Foundation

The foundation is very important as it bears the load of the superstructure. It is filled with sand and stones and is rammed strongly so as to get a hard base on which the house will stand. Flexibility on the foundation will cause sinking of the house. Besides serving as the base of the house it cuts off the continuity of moisture flow “Rising damp” and the movement of termites from the ground. This increases the durability of the house. The thickness of the foundation decides the thickness of the wall.

For making the foundation, an auspicious day and time was selected by the “*Brahmin*” who use to come in the white clothes, performs the ceremony “*Pooja*” by reciting some *Vedic* sermons and offering some sweets and flowers. Then he lays some material in the groove prepared for making the foundation of the house. Later the construction was done.

There was no conventional method for making the foundation. A groove is cut in the ground, which serves as a key to the wall, and will hold it. A course or two of random rubble is laid in it. It was believed that it would suffice the requirements of spreading the load of superstructure, water restraint, termite control etc. That has been proved for a number of years.

10.2.2 Walls

Walls being the load bearing elements are the main component of any building. The properties of the wall depend upon the materials used, design and the method used for construction. Such as; the grading of the sand and aggregates, binders (clay, mud, lime, gypsum etc), binder to the aggregate ratio, and cohesion of the binder to the aggregates, which was controlled by mixing the natural polymers. Thickness of the wall and the method used for construction (compaction) also play important role while considering the durability properties.

The mud house is generally constructed of earth available on the place. Water is added to the earth, mixed by foot and is left to weather. During this period it is kneaded by foot from time to time. By so doing the big lumps of earth breaks up and in contact with water they make a good uniform plastic paste. The plasticity is related to the maturity time which is judged by the able architect; mason on the site.

Use of Natural Polymers

When there is increasing demand on the durability of the house, natural organic materials, known as "Natural Polymer" [Chandra, 1994] have been used. These were carefully selected taking into consideration the climatic conditions prevailing in the particular region to which the material will be exposed. Material was selected by trail and error method done on the materials found in the vicinity of the area where the house is to be constructed. The details of the organic materials used are elaborated separately in Chapter 1.1, and Chapter 4; "Soil Stabilization and Natural Polymers". Natural Polymers are basically agricultural products and are therefore environmentally friendly. These partly interact physically and partly chemically with the soil, stabilize it and thereby make the construction durable.

These, when used with the binders enhance their physical and chemical properties. One of the most common material used was the leaves, hay, straw, coarse part of cereal (*Bhusa*) etc. These are only a few examples. The detailed list is given in the Chapter 4 "Natural Polymers". It looks very simple that the leaves have been mixed. But in fact if one looks at the constituents of the leaves, there are many components, which have been mixed. The leaves consist of wax- on the surface, by which the leaves do not get wet, chlorophyll, cellulose, carbohydrates, fibers etc. Each of these components play their role, such as fibers work like reinforcing agent and cellulose increases cohesiveness, plasticity etc.

Leaves are mixed with the earth and water and the mixture is left for weathering. This is kneaded by the foot from time to time. The process is repeated till the leaves become rotten. It is then very thoroughly mixed. By so doing the mud becomes plastic, cohesive and compact and becomes good mass to work with.

Walls with Mud and Lime

These houses are built in the similar manner except that lime is mixed in the mud in particular proportion (10-20%). By so doing the soil gains strength, gets stabilized and consequently its durability properties are significantly

improved. Details regarding the stabilization of soil with lime are described in the Chapter 1, "Stabilization of Soil". When the house is finished the walls are painted with lime wash. This further improves its durability to a great extent. In some places sand, stones and even the sun-dried lumps of clay are also mixed with the mud. It depends upon their availability of course. Like in the hilly areas there is abundance of stones. These are used together with the mud and sun dried soil lumps.



Figure 10.2 : Mud house with a thatched roof.



Figure 10.3 : Mud house built by casting the mud between the wooden forms.



Figure 10.4 : A thatched house built with mud and limewashed.



Figure 10.5 : Building with mud blocks.



Figure 10.6 : Double skinned sloping roof from Orissa.

It controls the drying of the wall and thereby the shrinkage, which leads to the crack formation and thus makes the walls strong and durable.

Raising the Walls

Earth thus prepared was cast over the foundation like the heaps. When the first layer dries, the other layer was cast over it. After the walls had attained appropriate height, the thatched roof, which was made of straw, grass and reeds was placed. It was a very primitive way of making a house. Such a house is shown photographically in Figure 10.2.

Building with Formwork

With a little better facility in materials and technique, the house is made even with the same mud but in a better way. This increases its life and its look becomes more symmetrical and thus pleasant. The mud is cast between the wooden planks, which are used for making a sort of mold for wall construction. Thus the thickness becomes uniform and the mud becomes well compacted. It is left for a day or two. When the mud dries, the wooden planks are shifted upwards, and the process repeats till the end of the walls. The windows, other openings and the doors are fixed up during the progress in the construction of the walls. The roof, which is made of straw, dry grass and reeds as is mentioned above but well compacted, is placed over the

walls. Sometimes split bamboo sticks or normal wooden sticks are inserted in the walls. These work partly as reinforcement and partly as a measure against burglaries. Some times small stones and sand is also mixed with the clay. This further strengthens the wall, the load bearing structure. These houses can be painted with a mixture of mud and cow-dung. This increases its resistance to water absorption and consequently enhances its durability. The thickness of the wall can be 45 cms. Such a house is shown photographically in the Figure 10.3. Figure 10.4 shows a house after lime wash. It is a normal practice to whitewash the houses after monsoon period before starting of Dewali. Legendarily it is to clean the house before *Goddess Luxmi Pooja* "Dewali" festival. But scientifically limewash provides extra strength and increases durability of the house. In addition to this, lime being insecticide kills the bacteria's grown due to the humidity and temperature in the monsoon period. Painting and limewashing is common even today not only in the rural areas but in the urban area's as well.

Building with Earthen Blocks

Building with earth blocks has been to shape the material by hand into lumps of convenient size and dried in air for a few days, then turned on their sides for a further few days. These are laid in the mud mortar in the horizontal position. This mixture for making them is the same as used for making earthen walls. In the warm climates it was possible to bake the clay lumps in the sun before laying them in the wall. This reduces the subsequent shrinkage leading to the crack formation in the wall (Figure 10.5).

10.2.3 Roofs

Roofs are constructed in different ways and with different materials for example; thatched roofs, earthen roofs, masonry roofs etc. Mostly the thatched and earthen roofs were used in the ancient period.

Thatched Roofs

The name thatch means an outer protective layer of some suitable vegetable material; not necessarily straw put on to the roof of a building. Later, it was more specifically associated with the straw and reed. The construction of thatch roofs will not be discussed here in detail. A short description of the material used for thatching is described. Mostly vegetable materials found close to hand have been used for thatching. The weeds and rubbish are first of all removed, and heather or sally is tied in bunches to the roof timbers with stout twine, and held flat with runners and spars. Miriam grass

(*Ammophila Arenaria*), a poor substitute for straw is used for making the roofs. Broom is a little easier to lay on the roof as the stems are straighter.

Red standard wheat, which has stems of bright yellow color, about 3 feet to 3 feet 6 inches long, is the most suitable. When prepared for thatching is often called "Reed", but is not to be mixed up with the marsh and river reed, which is too tough for thatching. The most common of thatching reed is *Arundo Phragmites*. Wheat straw instead of being threshed can be passed through a reed-combing machine, and being unbroken can be used for thatching in the same way as reed.

Earthen Roofs

Earthen roofs are not as common as earthen walls. But these are still found in a belt from Kashmir in the north to the Deccan plateau in the south, covering southern Kashmir, Punjab, Himachal Pradesh, some areas of Uttar Pradesh, Madhya Pradesh, Rajasthan and central parts of Maharashtra. In the south, earth roofs are found only in some parts of Karnataka and Andhra Pradesh.

Indian earth roofs are normally flat. These are constructed over a platform made out of wooden planks, reeds, and bamboo matting or stone slabs. Earth is beaten down and is occasionally plastered with a mixture of cow dung-earth and water. Sometimes leaves are also used as the fibers for the leaves work like reinforcement and thus prevents the earth from dropping through. Besides, the leaves give plasticity to the soil because of its cellulose content and thereby increase the adhesiveness and cohesiveness.

Double skinned sloping roofs are reported from Orissa (Figure 10.6). In this case, the earth roofs acts as a ceiling to protect the house from fire. A second, outer roof is constructed of grass and leaves over the slopping earth roof to protect it from being washed away by rain. In addition to this it keeps the house warm.

In the Kurnul area of Andhra Pradesh, flat roofs are formed by spreading sheets of stones over wooden beams and covering them with saline clay.

In the northern district of Karnatak, a layer of earth 2.5cm. thick called "*melmudde*" is rammed over matting of bamboo or reeds placed on wooden joints. Such a roof is more durable and requires repairs after 3 years.

In the wet climatic conditions of Kinnuar district in Himachal Pradesh, a flat earth roof known as "*Khayap*" is common. Layers of large leaves and local bushes are spread over thick wooden planks. Over this frame a 15-20cm (6-8 inch) thick layer of earth is carefully spread and beaten by small wooden clubs. Masons and others press the earth by walking on the

roof. Once the earth layer has been smooth and compacted, water is sprinkled on it. However, these roofs tend to leak in heavy rain during the monsoon period. In winter times, being in the hilly area it snows, which has to be removed quickly to avoid leakage, when snow melts and water accumulates or collapses due to the load of snow.

In some parts of Karnataka, earth is skillfully used to make the roof without the lower support of bamboo matting or reeds. Wooden joints are placed at intervals of about 23-30 cms. (9-12 inches) and small lumps of sun dried earth are placed horizontally on them. The earth cantilever grows till it covers the pace between the two beams. Holes are often made in such earth roofs for light. During rains, these holes are covered with earthen pots. In the Dharwar area in Karnataka, beautiful pottery chimneys are used to allow the smoke to escape.

In the houses with earth, stone, wood or brick roofs, the roof does not form a major visual element. By contrast, in houses with earth walls and sloping thatched roofs, the roof is the dominating feature.

10.2.4 Problems Encountered in Earthen Architecture

Earth is one of the most universally used building material. It is easy to build with it, and carries lesser problems than occur by the use of other materials. Nevertheless, it is not a durable material and needs continuous maintenance. But if made carefully it lasts for longer time. Therefore, it makes the necessity to preserve the earthen architecture. It reminds and brings continuity to ancient earthen architecture and carry forward the centuries old tradition and culture of the predecessors and the architectural history.

There are numerous problems associated with the earthen construction. Out of these important ones are physical and socio-economical in nature.

Physical problems are shrinkage cracks, erosion, under-scoring and mechanical damage. Most of these defects are due directly to water. Very often the effect of water on earth buildings has been totally destructive. Many villages of earth buildings have been washed away by floods. It does not mean that the buildings made with other materials are not effected. But those are comparatively more resistant to water penetration. If an earth wall becomes damp it may swell, on drying it may shrink and this may result in cracks. When these wetting and drying cycles continue for sometimes the cracks may be enlarged and the overall strength of the wall will be reduced. On further ingress of water into these cracks the strength of the building is further reduced. In some cases the building may also collapse.

2. Other problems related to water, particularly swirling rain water, are erosion and underscoring. The walls are eroded, the soil at the footing is gradually washed away until the building becomes unstable. Figures 10.7, 10.8 and 10.9 show respectively damages due to shrinkage cracks, erosion and underscoring of the foundations of an earth building. Erosion, however, is not only confined to wet areas. In semi-arid and desert regions erosion is also caused by wind laden with sand. These susceptibility of mud walls to mechanical damage is another disadvantage in building with earth. Even under dry conditions mechanical damage can occur. Under favorable conditions however, earth buildings have been known to have existed for centuries in certain parts of the world. In India, at Chan-Chan in Peru, and also near Sian Fu, ancient capital of China [Ideas 22, 1955] and in Kano, Northern Nigeria, there are many buildings which are believed to be many centuries old. Figure 10.10 shows a century old mosque built in earth, in Northern Ghana. Where there has been little or no rain the performance of earth building has been satisfactory. In fact, the durability of an earth building depends largely on the ability of the walls to resist water penetration.

Water being the main cause of rapid deterioration in earth building, the problem then is how to make these buildings adequately water-resistant. In finding a solution the properties of the soil, the design and the workmanship must be considered.

Soil Selection

Buildings made with earth have short durability. This depends upon the type of soil used for construction. Poor, not adequate choice of soils has always resulted in rapid deterioration of earth buildings. The characteristic network of cracks commonly seen on earth buildings is mostly due to soils of high clay content. Clays generally shrink and crack when dry and swell when damp, sand on the other hand crumble and erode easily when dry. In between these two extremes are clayey loams and sandy clays which have been found suitable. Nevertheless, it is difficult to select these soils as their properties vary considerably. Therefore, it is necessary to put restrictions on selection criteria for soils. Soils should be selected after prior testing. This should be simple in nature as majority of the clay builders are not highly qualified to understand sophisticated test methods. Further the criteria should be made taking into consideration the climatic conditions, especially when the durability of mud houses depends mainly on the properties of soil.

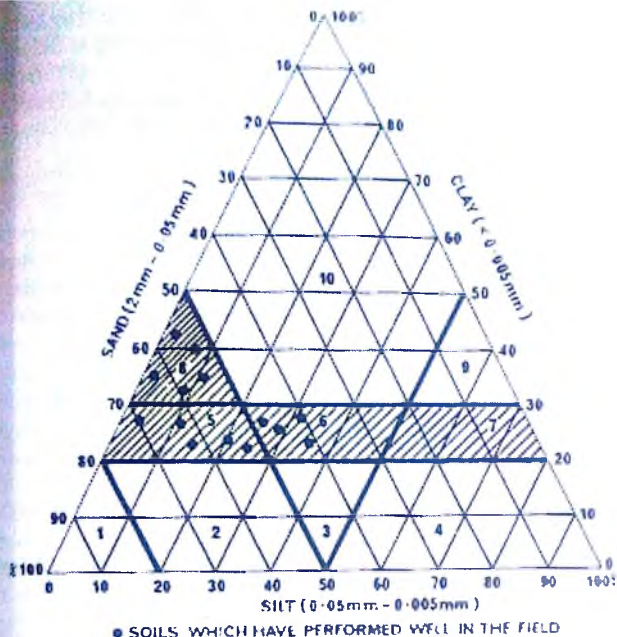
A classification of soil is given in Figure 10.11. Here different proportions of sand clay and silt of specified particle size are shown in a



Figure 10.9 : Severe under-scouring of an earth building due to swirling rain water and lack of concrete platform and gutter.



Figure 10.10 : 100 year old Banda NKwanta mosque in earth in Northern Ghana, [Museum and Monument Board, Ghana].



NO	CLASS	SAND %	SILT %	CLAY %
1	SAND	80-100	0-20	0-20
2	SANDY LOAM	50-80	0-30	0-20
3	LOAM	30-50	30-50	0-20
4	SILTY LOAM	0-50	50-100	0-20
5	SANDY CLAY LOAM	50-80	0-30	20-30
6	CLAY LOAM	20-50	20-50	20-30
7	SILTY CLAY LOAM	0-30	50-80	20-30
8	SANDY CLAY	30-70	0-20	30-50
9	SILTY CLAY	0-20	50-70	30-50
10	CLAY	0-50	0-50	50-100

Figure 10.11 : A textural classification chart of soils. The shaded areas represent soils for earth buildings [US Bureau of Soil Systems].

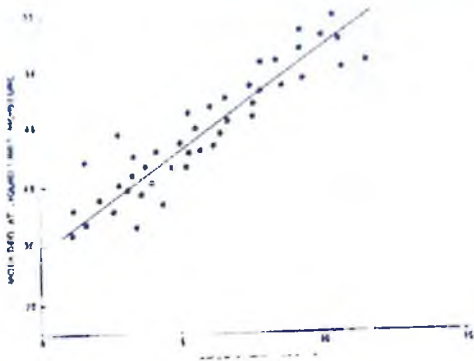


Figure 10.12 : Relationship between liquid limit and linear shrinkage of some lateritic sandy clays.

Design

Proper designing of the earth building is essential to achieve good durability. In fact very little attention has been paid to design a mud house which will resist water penetration. To safeguard the integrity of the mud house, protection against the rain and water penetration resistance becomes very important.

Foundation : From foundation to roof, architectural detailing becomes very significant. Erosion and under-scouring can be checked by means a good foundation design. Good results have been obtained by using concrete footing, concrete blocks, soil cement blocks and stones for foundations for mud houses [NSB 76, 1963, and NSB 84, 1965]. In areas where rainfall is heavy say about 80 inches (2 meter), it is desirable to have foundation height extending to at least 2 feet (60cm) above the ground level. Damp proof material should be placed in the wall below the finished floor line to prevent capillary moisture movement. Concrete platforms or aprons around the building have been effective preventive measures against erosion [Hammond 1972].

Roof : In designing roofs for mud houses long eaves overhang should be provided. Rain water gutters and a vertical "down pipe" should also be provided especially where rainfall is frequent and heavy, and verandahs should have floors designed in such a way as to throw away water from driving rain as

soon as it is collected. In areas where hurricanes are very common, where the tendency for the roofs, or overhangs to be lifted by the suction effect of the wind is great, all projecting features must be well tied down. [Oakley, 1961].

Roof leakage should be corrected as soon as it is detected and defective rainwater gutters and vertical down-pipe replaced immediately.

Lime washes : It is customary to paint the mud house with lime wash and paints. These can be good water proofing materials. These paints and washes can be oil based, resin based and emulsion based. Distempering, lime-washing and cement washing have all been used but have been more effective when the surface of the wall is weak, and specially in the dry area. Using paint and washes have many disadvantages. The paints and washes provide thin protective coating skin which makes the mud wall vulnerable to scratches, and abrasion. Flaking, peeling or scaling, blistering, crazing and bleeding are some of the defects occur, and the water-proofing effect is destroyed. In fact, the occurring of flaking, scaling and peeling indicates the presence of moisture in the mudwall. Bleeding, however, is a minor defect concerning discoloration and it is generally associated with bituminous materials. External surfaces of mud walls are better protected against rainwater penetration by both rendering and painting. Figure 10.13 shows a mud house with good protection against the elements.



Figure 10.13A : An earth building with good protection against rain.



Figure 10.13B : An enlarged portion of the eaves overhanging in Figure 10.13A.



Figure 10.13C : An enlarged portion of platform and gutter around the building in Figure 10.13A.

Selection of the Land

The people specially in India are superstitious. They believe in the superstitions. The land was purchased according to the old tradition, which is based upon astrology, and contains inscriptions from *Vedas and Purans*; the Indian Mythological Books. The Indian Architecture in Vedic literature is named as *Vastushastra*. The land was purchased only after getting the consent of

the wise people who had the knowledge about these matters. The detailed procedure adopted is described in Chapter 9, "Vastushastra".

Termite Attack

Foundation : One of the serious problem encountered is the termite attack. These can enter easily into the wall, foundation, and flooring and set up breeding nests and termite mounds. This can effect the timber in the building, the strength of the wall, and the living environment. Termite barriers at the plinth level can be useful. Using natural polymer, which worked as insecticide, solved this problem. For example mixing of the juice from "Sisal leaves" or leaves from *Neem* with the earth can prevent termites from entering the structure or by putting a layer of bitumen over the compacted sand and gravel in the foundation will hinder their way. Some of the natural insecticides are described in the Chapter 4, "Natural Polymers".

The site was selected so that the buildings were located on elevated grounds, rested on hard rock/hard soil outcrops. This solved the problem of water logging and termite attack. In fact even now an experienced builder in village has the knowledge to assess the quality of the site with respect to termites etc. Thus the emphasis is centered on the "local knowledge" based on the traditional skills and not on the theories repeated in the books.

If proper consideration is not given to these factors, an earthen building will face problems causing structure instability.

Flooring : Floors were rammed with earth in a traditional way and were finished with a coating of cow dung some times mixed with dry grass and water. Cow dung has antiseptic, anti termatic, anti bacterial properties and thus keeps away the flies and insects and thus protects the house. Besides this binds the loose dry particles over the floor and provides a smooth surface. But it is not long lasting and needs regular maintenance. Mud has different properties depending upon the source from where it comes from. For example, the mud taken from the "anthills" posses good waterproofing property.

Walls : The main problem associated with the wall is the moisture content. which influences upon the strength and the other durability properties. The moisture can be controlled taking into consideration the following parameters:

- Loading
- Permanent drainage
- Isolation of the structure by a rigid mass

- Retarding swelling by blocking moisture movement
- Keeping the walls to heat and cool uniformly.

Volumetric changes take place due to the plastic nature of the earth. It is generally solved by using straw along with the earth. Besides the use of straw there are some other materials also used in India which control volumetric changes, introduces hydrophobicity; reduces water absorption etc. These conclusively increase the durability properties of the walls. Some of them are mentioned here.

Wheat, flower stalk, hays : they control the shrinkage as by mixing them, the plasticity index of the mix is reduced. These also help in fast drying and provide better bond.

Cow dung : this posses all those properties mentioned above plus acts as antiseptic and insecticide.

Jaggery : It is a very sticky sugar cane product. It helps very much in increasing the adhesion.

Many organics have been used in pairs or in combination of others, which compensates the negative aspects and thus completes each other's fallacies. But if used alone, can cause insect and other durability problems. These problems are overcome by using poisonous juices like from cactus, fermented milk and straw etc.

10.3 Houses with Sun Baked Bricks

Sun baked bricks were used for more special and dignified constructions. The bricks were made in special way. The process and the material used for making the bricks are described in the Chapter 3. These bricks were used for making the walls and the mortar used for joining them was made of the mud and the organics. When the wall was finished it was plastered with the mortar made of mud and organic and polished. Thus it produced a monolithic structure with out cracks. The houses constructed with the sun-baked bricks are durable and stable compare to those made only with the mud. The durability of the wall is dependent upon the quality of the bricks. Special care is to be taken to produce the bricks. Bricks should be made in the spring or autumn, so that they may dry uniformly. Those made in the summer are not of good quality. The bricks dry very fast on the surface due to the high temperature prevailing in the summer time while the interior of the brick is still wet. This non-uniform drying causes shrinkage in the bricks and develops cracks. The bricks loose strength. The bricks should be dried slowly and uniformly. Older are the bricks better is the service life.

A house was found besides the northern apex, which was gutted in fire. Analysis of the debris has shown that the roof of the house was made of wooden poles, twigs and grass and was plastered over with straw-mixed earth. The houses were generally remained quite low in height as the thin walls indicated. For construction, besides those of the ratio of 3:2:1, there were a few bricks of square surface made into the ratio 3:3:1.

In the proto-Harappan period there were many abrupt changes in planning, architecture and antiquities. The entire settlement was enlarged into a bipartite township. All the pre-existing residential houses were raised to the ground and fresh ones were raised with the newly introduced bricks and with thicker walls of better workmanship. Bricks marked by a novel ratio of 4:2:1 were also seen.

In Harappan period all the walls were entirely made of molded bricks set in mud mortar and finally plastered over with mud mortar mixed with husk and dung. Further, the walls rose from a broader base with a taper on either side.



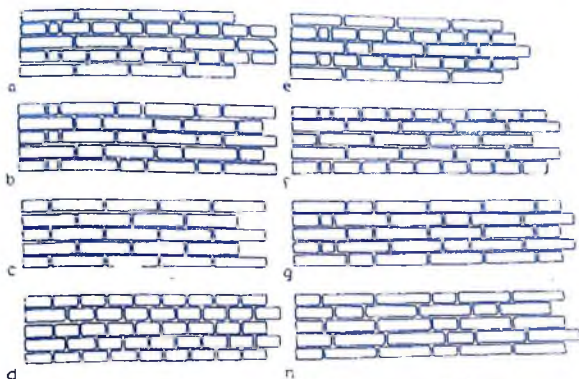
Figure 10.14 : Kalibanga, Pre-Harappan Period, 3000 B.C.

Dholavira

The wall was constructed using molded bricks in the well-known ratio 4:2:1 (Figure 10.16). In the latter stage, stage II, a 2.80m thick brick masonry wall was added to the pre-existing defensive wall from the inner side and the face of it was plastered over with fine paste of white and pink clays at least as many as thirteen times.

was made into a castle.

It is significant to note that through all the three stages, the inhabitants have shown their preference in the white and pink color clays for plastering walls, roads, streets or to the walls and floors of private houses.



Brickwork bonds: (a) English Bond, (b) Flemish Bond, (c) Stretcher Bond, (d) Header Bond, (e) English Cross Bond, (f) English Garden Bond, (g) Flemish Garden Bond, (h) Monk Bond.

Figure 10.15 : Alternate bond of headers and stretchers.



Figure 10.16 : Dholavira, Pre-Harappan Period cir 3000 B.C.



Figure 10.17 : Indraprastha in the vicinity of Delhi, cir. 1500 B.C [Verma, India Prospective, 1996].

The fortification walls, both inner and outer, were in fact solid structures made of proportionally molded mud bricks set in mud mortar. Successive courses of brickwork were laid in recessed order. As a result, both the faces were normally veneered with rubble and hammer-dressed stones; the inner ones were plastered over with fine clays periodically. At vulnerable places or near the gates the inner face also was provided with stone facing. However, the city walls were generally kept plastered with clay.

The city walls, particularly on the west and its adjoining quarters, played a crucial role. Apart from providing protection to the town, they functioned as strong "Bunds" made of millions of mud bricks- carefully laid in mud mortar. The inner peripheral road lined with stone masonry saved the walls from the water scoring as well.

Water reservoirs were also made with the mud bricks-laid in mud mortars.

Indraprastha

Excavations done by the Archaeological Survey of India reveal that the men lived in the area near Anangpur, and they lived in village known as Indraprastha, which lies in old Delhi. It shows the antiquity and continuity of Delhi. A fortification wall as is seen from the Figure 10.17 surrounded the village. It is clearly seen from the figure that the bricks have been used for in the construction of the walls. The estimated time of this construction is cir. 1500 B.C. The bricks used were of different sizes, which were laid in alternate rows of headers and stretchers.

These examples show that the bricks even after the exposure of more than 4000 years are in an acceptable durability condition.

Sun dried earth bricks usually handmade are becoming common in rural part. The bricks are larger than the kiln fired bricks. However there was no hard and fast rule and these did not conform to any standard size. Sun dried bricks usually made stronger walls than those made only using earth.

10.4 Burnt Bricks

During the early Harappan civilization, the main building material was baked bricks. The sun dried bricks, so much used in summer at the same period, is hardly ever found, and then only for the core of the walls and for the huts of the poor. Presumably there were still enough forests in this district to provide the fuel for kilns for baking the bricks. Otherwise it would have been impossible to produce the millions of cubic feet of bricks necessary for the building of Indus cities; Mohenjo-daro and Harappa. The walls still many feet high owe their excellent condition to this indestructible building material. This view of one of the narrow streets speaks about its durability (Figure 10.18).



Figure 10.18 : Narrow Street with straight walls on both sides at Mohenjo-daro (2300 B.C.)



Figure 10.19 : Baths at Mohenjo-daro made of bricks impregnated by bitumen (2300 B.C).

The lay out of the streets was similar to that of the most other of the cities, narrow alleys between houses with blank outer walls. The rooms in the houses were grouped around small inner courtyards, which provided light and air, and were one or two storeys high. Here it is clearly seen that the bricks used are of different sizes. The bricks in walls laid as stretchers are of different size than those on the double slits in the wall seen on the right side of the picture (Figure 10.18), which are laid as headers. These also seem to be of different quality. These are rubbish chutes. The household refuse was thrown through the sloping edge into rubbish bins in the street below through these slits, which was cleared away by the municipal refuse service. What were the real criteria for the selection of the quality and size of the bricks is not known.

The area shown in the Figure 10.19, which measures 9 ft. 9 inches deep and 42.5 x 19 feet in area was a water bath at Mohenjo-daro. Two sets of steps lead to the bottom of the pool and its walls are made water tight with bitumen.

The bricks made varied very much in size. There were very small size bricks, called "Lakhauri". These were about three and quarter of an inch thick, and normally about four by six inches. The word *Lakhauri* itself

comes from the word lakh. It mean lakhs (10 lakh= 1 million) of bricks for construction. Lakhauri bricks are seen in a wall at Nadan Mahal, in Lucknow (Figure 10.20). There were also larger and heavier bricks about two inches thick are known as pan patta. Figure 10.21 shows a big and heavy brick from a wall of an old building in Lucknow. There are also instances where curved bricks and triangular bricks were made. The triangular bricks were used for making the core of the statues. However there was no specific standard about the size. Smaller bricks, *lakhauri* owing to the great number used, gave tremendous strength to the structure. The other advantage is that they can be used both with the *pan patta* bricks and by themselves to form remarkably fine details even before the stucco has been applied. One such example is the construction of a complicated designed arch at “Karbala”, Lucknow, wich was accomplished just by using *lachauri* bricks (Figure 10.22). Mortar used for joining these bricks was very thin. Whereas the bigger bricks were laid with thick layer of mortar (Figure 10.23). The big bricks because of the bigger size work as load bearing blocks. Wood was used after 3-4 layers of bricklayers (Figure 10.24). This worked partly as the reinforcement, partly as expansion joint and partly against the burglary. Wood should have been of very good quality and pretreated. In many cases, the wood obtained after demolition of old buildings have been used for making doors, window panels etc.

10.4.1 Mortars for Joining Bricks

Mud bricks were laid in mud mortars and lime base mortar was used for joining burnt bricks. The walls and floors were plastered and later polished. The compositions of the mortars and plasters used in different historical buildings are given in the Chapter 6, and Chapter 7, for Plasters and Mortars respectively. The method of polishing and the material used with scientific explanation is given in Chapter 11. Now a days the bricks for making the houses in the urban areas are produced in the automatic factories, where the bricks are molded in the press, dried and burnt in the tunnel kilns with complete temperature control. The kilns are fired with furnace oil.

10.4.2 Masonry Roofs

Aggregates

The rejected or the old burnt bricks are broken manually in the small pieces. The broken bricks are shown in the Figure 10.25. Aggregates thus made are used for making the concrete with lime and clay or with only lime as binder. The aggregates made by breaking the bricks are porous unlike the

aggregates of stone. These are called *Bajree*. Thus, the bonding of the mortar is not just on the surface of the aggregates. The mortar penetrates inside the aggregates. This way there are no interfacial transition zones which are formed in the case of concrete made with the stones as the aggregates. Besides, the aggregate soaks part of the water. Thus the water to binder ratio becomes low. Moreover the aggregates keep the water. This slows the drying rate of the concrete. It reduces the plastic shrinkage cracks formation. The concrete made with these types of aggregates produces a strong and monolithic structure.

Roof Construction

Roofs made over the burnt brick walls are cast by concrete made with crushed burnt bricks, lime and sand. Concrete is made using particular proportion laid by the skilled masons. The roof is made by laying wooden beams over the walls. Small square wooden pieces "*Jhanpe*" are put over the spaces in between the beams. The aggregates and sand mixture "*Bajri*" is put over the wooden pieces and is compacted by the wooden stick "*Mugri*". When compaction is complete which is decided by the skilled mason concrete is poured over it concrete made as is mentioned above is cast over it. It is covered with wet jute bags, cloth etc. Some organic additives like *Urad ki daal* and *jaggery* is also mixed in the concrete. This provides better adhesion and higher strength. This also enhances the durability of concrete against rain.



Figure 10.20 : Lakhauri brick wall at Nadan Mahal, Lucknow, [Photo, Chandra 1999].



Figure 10.23 : Bigger bricks laid in thick mortar, for wall construction at “Karbala”, Lucknow, [Photo, Chandra 2000].



Figure 10.24 : Wood laid after 3-4 layers of the bricks.

10.4.3 Palacial Buildings with Bricks- Architecture of Lucknow

In the Mughal period, 11th century, it was popular to build the buildings in marble but in the places where there was scarcity of marbles, imitation was done with bricks and stuccos. There exist many renowned building in Lucknow which are constructed using burnt bricks and lime mortars. Typical example is the pillars at the Art Gallery, in Lucknow, which were constructed of bricks, *Surkhi* and lime mortars (Figure 10.26). In spite of extensive use, there was no standardization of the bricks or the mortars. It depended upon the wish of the supervisor at site. There was a gap between planning and actual realization of the work. Thomas Williamson wrote in the year 1810 [Fatal Friendship]:

“Some of the Rauz, or bricklayers, in India, are very clever, so far as relates to mere practical operations; but they have not the smallest idea of planning from paper, or on paper.”

It is of great interest to look into the materials and the way they were used in Lucknow. This speaks about the intelligence and the vision of the supervisors controlling the work.

Burnt bricks were used in building the houses of well to do persons, the Nawabi palaces and the religious buildings. A building made of burnt bricks, i.e. bricks that had been kiln fired, was called “*Pukka*”, while the building made of sun-dried bricks or mud blocks was called “*Kutcha*”.

The erection of a typical nawabi *pukka* building was a slow process. First a deep foundation had to be dug, not just because of the soft and friable nature of the soil and the weight of the proposed superstructure but because the basement or the semi basement rooms embedded in the soil were valuable as retreats during the summer season. These rooms, the *tykhana*, had small downward pointing shafts near the ceiling to provide light and air, but not directly sunlight. The floors of such basements were of considerable thickness, constructed of the layer of bricks and cement with flues inserted at regular intervals for drainage, although two rows of inverted pots were sometimes substituted (Figure 10.27), packed round with sand or coal, which was then covered with a layer of tiles and cement. Wooden beams were not used at all at this level because of the fear that the imperfect drainage may damage the wood in the monsoon period.



Figure 10.25 : Crushed bricks for use in making lime base masonry, [Photo Chandra, 1998].

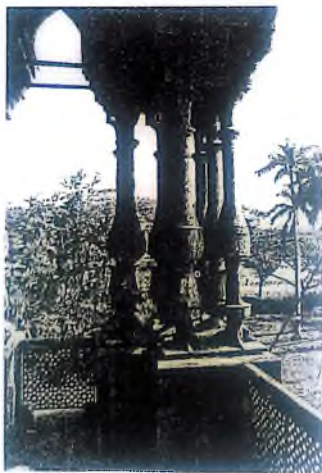


Figure 10.26 : Pillar made of bricks and red lime mortar; imitating red marble, Picture gallery, Lucknow, [Photo Chandra, 1998].

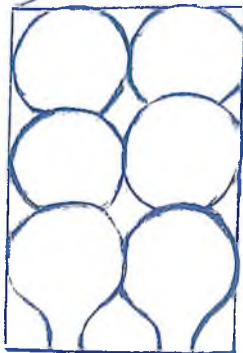


Figure 10.27 : Two rows of inverted pots, in between the walls.



Figure 10.28 : Rumi Darwaza, Lucknow [Photo Chandra, 1998].

All the walls were made of solid masonry of enormous thickness. The partition walls were even 2 feet in breadth. These are composed of solely *lakhauri* bricks and cement. Some solid walls in Constantias measure five feet across. Where walls have been partially robbed for their bricks one can observe that they are indeed solid masonry, with no rubble core. The only exception are the outer walls of Constantia and Barowen which incorporated pottery ducts as air-cooling devices cemented into the walls. Over the wall beams are placed. Over the beams were placed wooden joists or battens of thinner wood, and across these joists were laid flat pottery tiles, cemented in place. Normally two layers of tiles were used each sandwiched with cement. Then 4 to 5 inches of rubble or mortar was laid on top of it before the final coat of mortar was laid, which would then in turn be stuccoed over and polished. Conventional wooden board floors were seldom used because the underside of the boards would not be visible for visual inspection of damage caused by white ants and the damage because of warping. Most buildings were of no more than three complete storeys, including the semi basement, though they often incorporated a smaller fourth story over the center of the building, as in the Dilkusha, and Constantia has six storeys.

Once the masonry had been completed wooden lintels and frames were inserted where appropriate, and doors, windows, and shutters were hung "invariably painted green". Some preferred all verdigris, other, a deep clear green for the framework, with verdigris for several leaves or valves. Windows were normally made of glass as it was cheap, and readily available in Lucknow. Inside the building were the circular staircases, always surmounted by a masonry stairwell.

Even the building as palatial as Asif Kothi continued the tradition of small staircase. Until 1780 most staircases were built in masonry, but wooden staircases then came into use. "These rest on strong wooden beams. All joist were painted or tarred. Many nawabi buildings have iron rings on the ceiling level, both inside and outside, where cloth could be hung. *Punkhus* (fans) were attached to the ceiling beams by iron rings, and the varandah roof.

Inside the house, after the walls had been stuccoed and the ornamental moldings made, delicate colors like lilac and sky blue were applied, often with the molding and beading of the mock door panels picked out in white. Many nawabi houses still retain conventional European fireplaces with wide flues, but one must conclude from the complete absence of the chimneys at roof level that such fireplaces were purely decorative or, what is more likely, that they held movable braziers of charcoal during the winter.



Figure 10.29 : Asafi Imambara, Lucknow.



Figure 10.30 : Chota Imambara, Lucknow [Photo Chandra 1998].



Figure 10.31 : Ballieguard, Lucknow.

The stucco used was of very special type. Lucknow workman believe that the stucco used in the famous architects including “Jama Masjid” was made from red lime, gum, a kind of fine pulse called “*Urad ki Daal*”, Jaggery, shells and a resin called *Saras*. These organic materials are described in detail in the Chapter 4 “Natural Polymers”. The composition of *chunam* could vary considerably according to the pocket and the taste of the builder. The *nawabi chunam* of Lucknow was especially commended upon and a few examples of marble like *chunam* remains, for instance in the Residency Banqueting Hall. However, *chunam* in other parts of India like Udaipur and Jaipur in Rajasthan, where marble is used, is consistently better preserved and is of highest quality.

Stucco could be used to produce effects in quite deep relief, even applied to a flat wall, as in the pediment on the Husainabad well where figures in Graeco-Roman style are molded to produce a two dimensional effect without relying on a skeleton of brick or iron. Similarly the false domes which appear on the walls in the Asafi Imambara, and the Residency complex Begun Kothi in Lucknow are very characteristic of the eighteenth century nawabi architecture. These are built in stucco to a smooth wall and not built up over a brick core. Some of the buildings constructed of bricks and lime stuccos are shown in Figures 10.28-10.31.

Concluding Remarks

The author wants to emphasize here a few things, which were normally adopted in the construction in the ancient period; selection of ingredients for making mortars and concrete, specifically the natural polymers, and the method used for preparing them. The ancient builders were very much particular in application technique. Natural polymers were seldom used as

one component. Two or more were used at the same time. This was done to compensate for the negative aspect of one polymer. Like the use of only Casein is not good, it creates fungus problem. But if used together with the oil, it produces exceptionally good results.

The palaces and the buildings of importance were constructed, with double walls and double roofs. In between them two rows of inverted pots were placed, which were packed with crushed coal or ash. This way, the inner roof and the walls are not affected by the outside atmosphere. Apart from this, the moisture and the salts are absorbed in the coal and the earthenwares. Thereby, the building is not faced with moisture, and salt problems. The paintings are protected. This also provides insulation to the building, and solve the acoustic problems. Besides this they use to make a cavity at a distance from the bottom of the floor. This allows the drying of the moisture, which may be present inside. This also creates discontinuity of the moisture movement, particularly the rising damp. Wood was used as a reinforcing material. This has spared the structure from the corrosion problems, which ought to come due to the use of iron as reinforcing material.

It is very interesting to note that in ancient period the builders were very much foresighted and have used the material and methods, which will not create the problems at the later stage.

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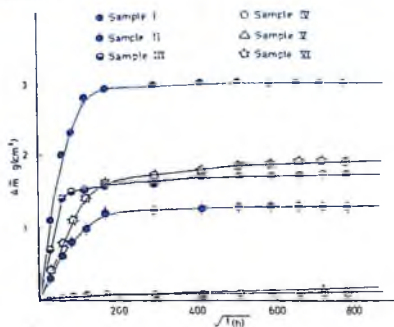


Figure 12.1.1 : Water absorption by capillarity [Singh et al. 1990].

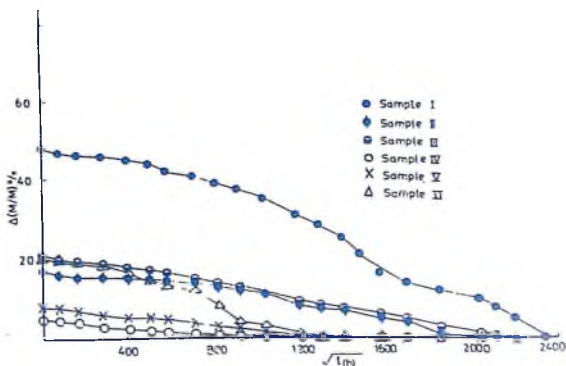


Figure 12.1.2 : Rate of water evaporation from the samples [Singh et al.1990].

12.2 Building Materials using Low Cost Resin from Plant-based Products [Jain 1986].

Jain [1986] has done a survey on the use of low cost plant base resin produced by cashew nut liquid on the building materials. The work has been conducted in the University of Roorkee, India. Some of work is highlighted here.

Cashew Nut Shell Liquid (CNSL) is obtained from cashew apple by solvent extraction or by heating the shells. An estimated annual production of cashew nuts in India is around 2 lakh tonnes which may yield about 50 000 tonnes (82% by weight) of cashew shell liquid every year. Commercially available liquid mostly contains cardanol. It is chemically very reactive. CNSL aldehyde resins have been used as adhesives. The resin obtained from processing of CNSL could have a little variation in properties by virtue of methods of processing i.e., alkaline or acid medium of process. The product in all cases cures to a solid or semi solid material at room temperature. It has been observed that this resin has superior resistance to depolymerization and /or oxidation c/d to coal tar and bitumen. A variety of products having applications in buildings have been developed and their performance over last decade indicate that the products compare reasonably in weatherability with the sophisticated materials like epoxy, urethane etc. The cost of CNSL resins is about 1/4th of the synthetic resins. This makes it more attractive.

12.2.1 Expansion Joint Filler [Jain et al. 1964]

Cement concrete slabs show thermal movement about 4cm for 100m length. To accommodate this movement space is provided between the slabs and this space is filled up by expansion joint filler. A suitable composition for use as expansion joint filler was worked out using CNSL based resin and coconut pitch [Jain et al., 1964], a waste product of choir industry. Available to tune of 400,000 tonnes per annum. The process of its manufacture is simple and requires no specialized instrument. The product meets the requirements of the relevant Indian Standard Specification.

12.2.2 Water Weather-Proof Coating [Jain and George, 1969]

Water leakage through roofs is very wide spread problem in the tropical countries, where rainfall is high and the bitumen/ coal tar based felt has miserably to the extent that not more than 3-4 years life in majority of cases is obtained. Further, this damage tar felt adds to the problem of leakage after it is weathered and also its replacement is costly due to messy cleaning problem. An exterior grade plastic surface coating was developed based on CNSL [Jain and George, 1969] for application on wood and masonry surfaces. The treatment is specifically designed by using an alkaline medium product for masonry work and acid medium product for wood based products. The treatment has withstood 10 years of exposed weathering when applied on particle-board in which 4% leafing aluminum pigment was incorporated.

The color also became deep grey so was more appealing. The test samples on masonry withstood 1000 hours of artificial weathering with out showing any deterioration. The test for water vapor transmission for pigmented and unpigmented films (according to ASTM E 96-66) gave very low values as such indicating a satisfactory performance.

12.2.3 Low Density Polymer Concrete **[Gangopadhyaya et al., 1985]**

Various problems associated with the prevailing heat insulating and water proofing treatments over thick roofs in tropical countries are well known. In order to find a suitable solution to these problems an attempt was made to develop a rational, efficient and functional alternative treatment [Gangopadhyaya *et al.* 1985] utilizing low cost resin based on CNSL and lightweight aggregate such as bloated clay or cinder; a railway waste. Though the results of study carried out so far have been found satisfactory, the material cost is around 60 Indian Rupees per sq. m. It is expected that it is a good waterproofing material in this price range and is best suited for the developing countries.

12.2.4 Anti-Corrosive Treatment for Building Materials

CNSL resins have been found to be compatible with epoxy resin and simultaneous polymerization of two resins has been successfully carried out to yield interpenetrating polymer network system (IPN) for use as low cost and better performing polymeric systems for building materials in fertilizers and chemical industry. These systems have been found to behave better in physical properties.

This shows that a number of useful products are possible to develop from materials based on plant products which have application in improving the performance of buildings at reasonable price.

12.3 Influence of Black Gram Addition as Admixture in Cement Mortar and Concrete **[Chandra and Aavik, 1983]**

Black gram was tested in the Portland cement mortar and lightweight aggregate concrete. Soaking it in water made black gram paste and grinding it so as to pass sieve 0.125mm (Figure 12.3.1). Black gram-oil emulsion was made by mixing edible oil to the gram paste. Cement-sand mortar (1:3) was made with gram and gram+ oil emulsion. Varying the water to cement ratio fresh densities were measured and the air content was calculated.

Mechanical strengths and water absorption were measured. It is shown that the black gram works as a multi purpose chemical admixture. It entrains air, which increases with the increase in the dosage of the black gram (Figure 12.3.2a-b). With the addition of oil+ black gram emulsion the air entrainment decreases significantly. Further, it is seen that inspite of the air entrainment the strength of the concrete is not decreased. On the contrary it is increased. However, the increase is not substantial. It shows that it has good adhesion property (Table 12.3.1 and Table 12.3.2). This also introduces hydrophobicity in the concrete which is seen by the decrease in the water absorption of mortar and the lightweight aggregate concrete made with its addition (Figures 12.3.3 and 12.3.4).

Black gram constitutes of proteins, which contain hydrophilic and hydrophobic part. During the hydration process the hydrophilic part of the protein interacts with the hydrophilic surfaces of the hydrated cement paste whereas the hydrophobic part became exposed to the air-cement interface in the pore and capillary structure. Thus the hydrophobic inner surfaces of pores and capillaries are obtained. The interaction of hydrophilic part of proteins with cement is increased by the reaction of Ca^{+2} ions with the carboxylate groups present in the proteins as is hypothesized by Chandra [Chandra *et al.*, 1981].



Figure 12.3.1 : Wet grinding of black gram, [Chandra, 1981].

were polished using metal trowel while spraying the surface with a little amount of water. The trowel was rubbed hard against the stucco surface in order to obtain a smooth, compact, and less permeable surface. Subsequently the panels were painted with the stabilizer solution that was used for making the stucco. Fungus appeared on the surface during the first days, but disappeared when the stucco panels dried out.

12.5.2 Tests for Water Resistance of the Stucco

In this test the stucco panels were subjected to several cycles of simulated rain test by using a lawn sprinkler connected to a hydraulic system. At the end of the test, the eroded material was collected in a tray, kept under the stucco specimen (Figure 12.5.1). The panels were subjected to 20 cycles of simulated rain, each cycle being composed of 3 hours of a heavy rain shower followed by a 21 hour of outdoor drying. The test was stopped earlier if the accumulated eroded materials exceeded 10% of the initial weight of the stucco panel. In addition to recording the weight loss at the end of the tests, the damage suffered by the specimens was also visually rated as light, moderate or severe. The tests were conducted inside an enclosure in order to avoid variations in the water pressure due to wind. The panels are shown photographically after the simulated rain test in Figure 12.5.2

The stucco panel of the plain soil caused extensive damage only after 30 minutes of exposure. The test was stopped after 9 cycles when the amount of eroded material had reached the specified limit of 10% of the weight of the specimen. On the stucco containing cactus stabilizer, it was observed that the water flowed easily on the surface due to the excellent finish, which was compact and smooth. However the finish was lost gradually due to erosion around zones of microcracks, but the loss of material was nominal. The stucco stabilized with banana solution lost slightly more than 5% soil in the 20-cycles rain test, the stuccos containing asphalt emulsions and cactus solution performed much better. The stucco containing 2% asphalt lost about 1% soil in 20 cycles of the test, however, both the stucco with 4% asphalt and with cactus stabilizer lost very little material (0.5% or even less).

It can be concluded from these tests that the drying shrinkage cracks created areas of weakness where subsequent damage occurred during the rain. It is shown that the moisture resistance obtained with the addition of cactus solution is comparable to the stucco containing 4% asphalt. The stucco polishing of the surface has added to its resistance to erosion. It was especially effective in the stuccos containing stabilizers.

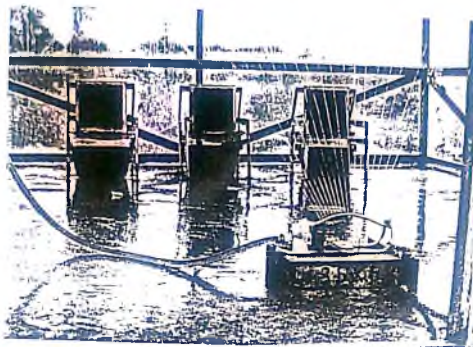


Figure 12.5.1 : Simulated rain test.

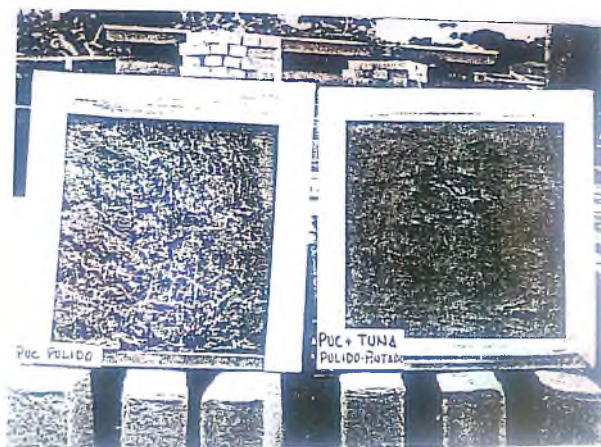


Figure 12.5.2 : Visual appearance of the stucco panels after the rain test, Left: plain soil stucco, Right: stucco containing the cactus stabilizer solution.

Conclusions

It is concluded that it is possible to obtain a crack-resistant stucco composed of the soil, a coarse sand, straw, and a viscous solution made from the cactus plant. The impermeability of this stucco can be further enhanced by stone polishing the surface.

12.6 Influence of Vegetable Oils Addition on Portland Cement [Chandra *et al.*, 1996].

Oils have been used in ancient period to enhance the durability properties but their form and the way of mixing is not fully known. In this work three types of vegetable oils: Linseed oil, Corn oil and Mustard oil were mixed in Portland cement mortar. The oils were used both as raw oil and also after being cooked. Mechanical strength, water absorption and freeze salt resistance have been tested. It is seen that the oil addition, even in so small as 0.5% to the weight of cement substantially decreases water absorption and subsequently freeze-salt resistance is increased. Increase in the amount of oil addition from 0.5 to 0.8% further improves the resistance to water suction and freeze-thaw resistance.

Linseed oil : It is yellow-green color oil and is made by pressing linseeds. It has high content of lanolin acid. It has many unsaturated fatty acids with 18 carbon atoms and two double bonds.

Corn/Maize oil : It is yellow color oil and is made by pressing or extraction corn, which contains 40-50% fat. It contains many unsaturated fatty acids.

Mustard oil : It is light vegetable oil of yellow color and is made by pressing or extracting white mustard seeds. It contains iso-cynates ($R-N=C=S$) which give specific smell, characteristic of mustard oil.

In this study 0.5 and 0.8 %oils were mixed in 1:3 Portland cement mortar using 1,2,3 standard sand with a constant water to cement ratio of 0.5. Fresh densities of these mixes were determined. 40 X 40 X 160 mm. prism samples were made. These were cured under water for 5 days and in the climate room for 23 days at 20 degree centigrade and 55% RH. Flexural and compressive strengths were measured after 7 and 28 days.

The results are shown in Table 12.6.1, for 0.5% oil addition and in the Table 12.6.2, for 0.8% oil addition. After 28 days curing the samples were dried out to constant weight at 105 °C. Water absorption of these samples was tested after cooling to room temperature. The results are shown in Figure 12.6.1 for 0.5% oil addition and in Figure 12.6.2 for 0.8% oil addition.



Figure 12.8.1 : Water drop on the surface of lime sample.



Figure 12.8.2 : Water drop on the surface of lime + sand sample.

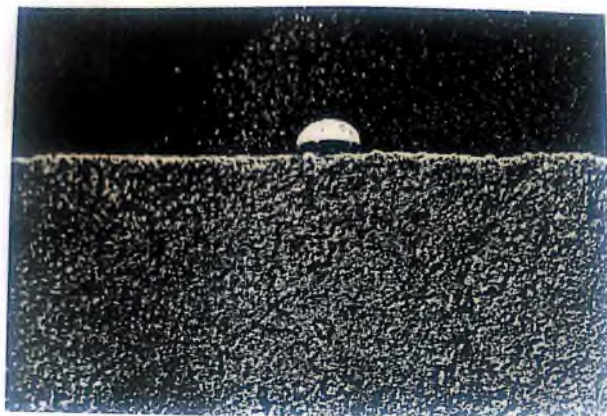


Figure 12.8.3 : Water drop on the surface of lime + sand + **Black gram** (Urad dal).



Figure 12.8.4 : Water drop on the surface of lime + sand + **Neem oil sample**.

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ISBN: 81-883